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KC-135 CREW REDUCTION FEASIBILITY DEMONSTRATION SIMULATION STUDY VOLUME 3: TEST AND EVALUATION

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This technical report has been reviewed and is approved for publication.

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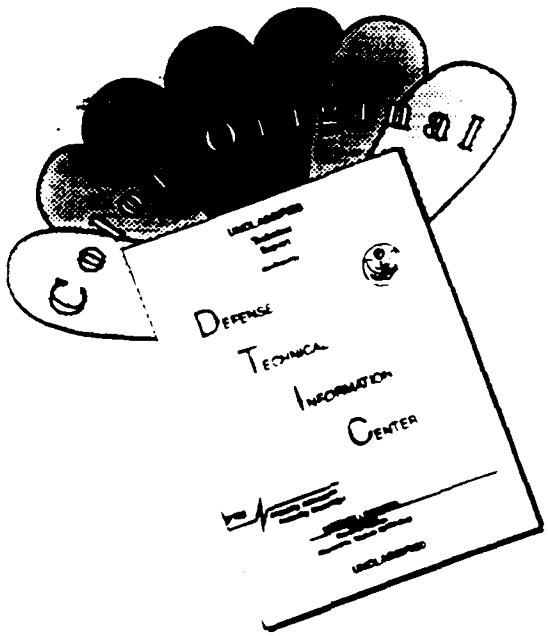

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In support of the KC-135 Avionics Modernization Program, a two-person (no-nav) conceptual cockpit design (Vol. 2) was evaluated using man-in-the-loop simulation. This report is Volume 3 of a 3-volume technical report. The objectives of the study were twofold: (1) To demonstrate the feasibility of the design and (2) Given the feasibility, to generate the functional requirements necessary to make such a design work. These requirements could later be used by SPO engineers as an aid in developing specific specifications.

The simulation used 10 KC-135 crews and 2 KC-10 crews to demonstrate the feasibility of the design. Each crew was required to fly several missions over a period of 1 week. Subjective and objective measures of performance and workload were taken during and after each flight. The subjective workload measures (Subjective Workload Assessment Technique - SWAT, Subjective Workload Dominance (SWORD) technique and the Modified Cooper-Harper scale - MCH) and the various performance measures (i.e., airspeed, altitude, time control, etc.) provided convergent results supporting the feasibility of the conceptual design. Questionnaire data provided an additional analysis for determining those functions/subsystems deemed necessary for mission success. Recommendations of the functional requirements are discussed.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | **Page**

Figure **Page**

INTRODUCTION

The USAF currently foresees the continuing need for the KC-135 aircraft fleet and, consequently, has embarked on an avionics modernization program. The Strategic Air Command (SAC) issued a Statement of Need (SON, 1987) addressing its need for modernizing the KC-135 cockpit avionics. SAC stated the avionics systems currently installed need updating since a large percentage of the current avionics are late 1950s and early 1960s technology (e.g., vacuum tubes, mechanical analog displays). Consequently, the outdated technology has degraded the efficiency, reliability, maintainability, and safety of the KC-135 mission.

The Avionics Modernization Program (AMP) represents a shift in philosophy from reacting to urgent deficiencies to planning for anticipated requirements. The long-range goal of AMP is to develop a systematic time-phased avionics integration by means of modification blocks (Mod Blocks) that will ensure all avionics upgrades are installed in a manner that will optimize follow-on upgrades. This integration plan emphasizes the use of modern technologies while maintaining commonality with other Air Force weapon systems.

Current technology allows the KC-135 to be updated with avionics that have significantly higher levels of reliability and maintainability, thereby reducing life-cycle costs and increasing mission reliability. A fully integrated avionics system can also allow for increases in mission management efficiency and automation, simplified crew interfaces, as well as enhanced navigation, and reductions in overall crew workload. Accordingly, the reduction of the current crew configuration (pilot, copilot, navigator, and boom operator) to that of a crew with no navigator might be feasible resulting in an additional savings in manpower costs.

The possibility of a KC-135 crew reduction has also been addressed several times in the past. Gieselhart, Schiffler, and Ivey (1976) conducted a series of flight tests with dual Inertial Navigational Systems (INSs) installed aboard a test aircraft. They concluded that with this minor upgrade plan, workload was too excessive for the exclusion of the navigator. Schiffler, Geiselhart, and Ivey (1976) reviewed task analysis documents and performed flight tests before similarly concluding that a four-person crew was necessary.

However, more recent efforts have shown that crew reduction can be accomplished effectively. For example, Schiffler, Geiselhart, and Griffin (1978) used flight tests to demonstrate the C-141 aircrew could be reduced from its crew of five to four without significant mission degradation. Accordingly, the C-141 aircrew was reduced in size and currently has no navigator on board. In 1981, Barbato, Sexton, Moss, and Brandt used a KC-135 cockpit design study to determine avionics control and display criteria needed to successfully accomplish a mission. Their study used complete state-of-the-art systems to conclude a KC-135 crew reduction was feasible given a completely updated and redesigned cockpit. Madero, Barbato, and Moss (1981) used the previous study and subsequent system evaluations to develop a composite configuration that was evaluated in a full mission simulation. They concluded the KC-135 mission could successfully be accomplished using a three-person crew. Although, the studies cited indicate mixed results, the more recent studies call for a completely redesigned cockpit as necessary for mission accomplishment given a crew reduction.

CSEF Tasking

The Crew Station Evaluation Facility (CSEF) operated by the Aeronautical Systems Division Human Factors Branch (ASD/ENECH) conducts real time engineering simulation evaluations in support of weapons system development. System Program Offices (SPOs) use the CSEF as an engineering tool for quantitatively and qualitatively assessing the flight crew's performance as a function of crew complement, crew station configuration, and operational mission.

As part of the KC-135 Avionics Modernization Program, a Memorandum of Agreement (MOA) between the Directorate for Bomber and Tanker Programs (ASD/SDB) and the CSEF was signed in October 1990. The CSEF was tasked with exploring the feasibility of a reduced crew size by developing an advanced cockpit design and avionics update, then demonstrating the feasibility of that design in a full mission simulation environment. The CSEF accomplished this tasking in a three-phase effort: (1) Function analysis phase (Volume 1), (2) Cockpit design phase (Volume 2), and (3) Test and evaluation phase (Volume 3). The task analysis, design, and evaluation efforts were, by intent, separate efforts conducted to identify items of interest such as workload bottlenecks, safety-critical tasks, etc.

Function Analysis Phase

The function analysis phase focused on breaking up tasks into categories and describing the who/what/where/why/how of each function/task (Ward, Dudley, Hassoun, Hughes, Rueb, & Conroy, 1991; Vol. 1). The crew positions were broken up into duties, large segments of work performed by an individual crew member (e.g., celestial navigation), or into tasks, distinct work activities carried out for a specific purpose (e.g., alter heading line entry in the navigator's log). Additionally, high workload segments of the mission were identified to aid the design team in determining areas to focus on. This information was gathered via literature searches, questionnaires, interviews, and observations. Based upon the information gathered, a working group composed of two pilots, two navigators, two human factors engineers, and one industrial psychologist recommended how the various duties and tasks should be reallocated and/or automated (functional requirements). The recommendations of this phase were used during the design phase for determining which systems/displays should be used.

Cockpit Design Phase

This phase focused on designing a two-person conceptual cockpit to eliminate the navigator from the cockpit (Barnaba, Rueb, Hassoun, Dudley, & Ward, 1992; Vol. 2). The design effort used the functional requirements identified above supplemented by a number of other sources. User/customer requirements were a major consideration, while vendors of Cockpit Display Units, flight computers, etc., were also consulted to ensure current innovative technologies were considered. In addition, several of the design team members were experienced participants in earlier KC-135 (and other aircraft) advanced developmental projects.

The final design used a Rockwell International-Collins Avionics developed approach as its baseline with significant modifications implemented by the CSEF team. These modifications were based upon sound human engineering practices and comments from preliminary "quick looks," where several KC-135 crewmembers were shown different design configurations and asked to comment and make design and location recommendations. These items were provided to the test and evaluation team (Vol. 3) for their consideration.

Test and Evaluation Phase

During this phase, the CSEF personnel attempted to demonstrate the feasibility of the two-person conceptual cockpit developed during the design phase (Vol. 2). The final design configuration was demonstrated in a simulated environment using operational aircrews. Each aircrew flew four different simulation missions with varying levels of crew workload. Pilot performance data, as well as subjective questionnaires and oral responses, were collected. Given the feasibility of the two-person cockpit configuration, this phase would also determine the functional requirements necessary to keep workload levels manageable for successful mission accomplishment.

This volume describes the method and results of the test and evaluation phase of the effort. Design recommendations, lessons learned, tradeoffs, and other considerations are also included to provide guidance to SPO engineers and managers when developing human factors and crew station requirements for KC-135 improvement programs, especially those involving crew reductions. The approach used to develop the cockpit design for simulation, including the ground rules and assumptions for this development, is also discussed. For a detailed description of the design, refer to Volume 2: Cockpit Design Report (Barnaba, Rueb, Hassoun, Dudley, & Ward; 1992).

METHOD

Subjects

A total of 10 KC-135 crews (pilots (P), copilots (CP), and navigators (N)) and 2 KC-10 crews (pilots and copilots) were used. They were operational crews from various air bases (Active, Guard, and Reserve) throughout the United States. All of the crew members were qualified in their positions.

KC-135 Pilots

The resulting personal data indicated the subject pool was relatively older (x=30.4) and more experienced (average total flight hours=2249 and average total KC-135 flight hours=1237) than the current operational force based upon the subjective judgment of the subjects. The pilots' average time since last flight was 9.5 days.

KC-10 Pilots

Similarly, the KC-10 pilots were relatively older (x=31) and more experienced (average total flight hours=2450 and average total KC-10 flight hours=1220), than the current operational KC-135 crew force. The average time since last flight was 4.5 days. Two of the pilots had previous KC-135 experience and one had been a KC-135 navigator prior to becoming a KC-10 copilot.

Apparatus

Simulator

The KC-135 simulator, shown in Figures 1 and 2, included such major components as the control loading assemblies, seats, yokes, and visual windows. The simulator was equipped with two wide angle collimating windows that provided a panoramic outside scene capable of supporting the CSEF Night Visual System (NVS). A Digital Equipment Corporation (DEC) PDP 11/35 computer used one of a number of databases to generate sets of lights, simulating various night visual scenes, for the NVS. This provided the subjects with a visual capability used during takeoff and during approach and landing. The KC-135 simulator cockpit was a newly designed conceptual cockpit. The actual instrumentation used and its description can be found in Volume II (Barnaba, Rueb, Hassoun, Dudley, & Ward; 1992), which describes the entire cockpit for both the pilot and copilot positions. The software package contained all flight, engine, atmosphere, weights and balances modules; a dictionary of all KC-135 data variables; and several other specific commons and data pools for the KC-135A model aircraft. In addition, a computer program read a Defense Mapping Agency (DMA) terrain database into memory of a Gould Sel 87 computer. The elevation of the terrain was then computed based on an extrapolation of the simulator position in relationship to the database. The subtraction of the terrain elevation from the aircraft barometric altitude (computer based) provided the above ground information fed back to the aircraft radar altimeter indicator.

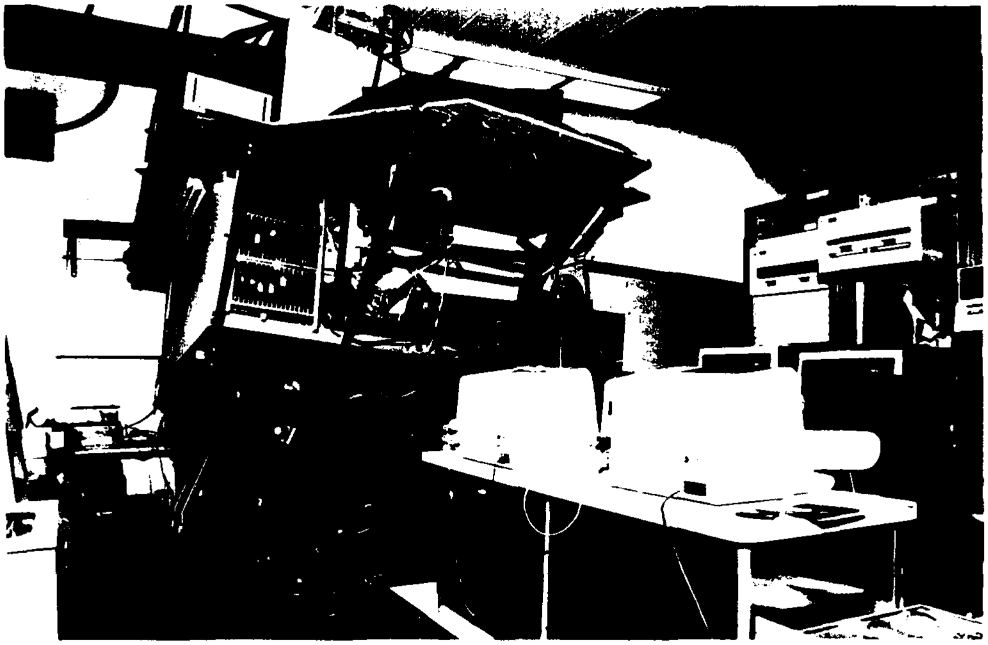

Figure 1. KC-135 simulator exterior.

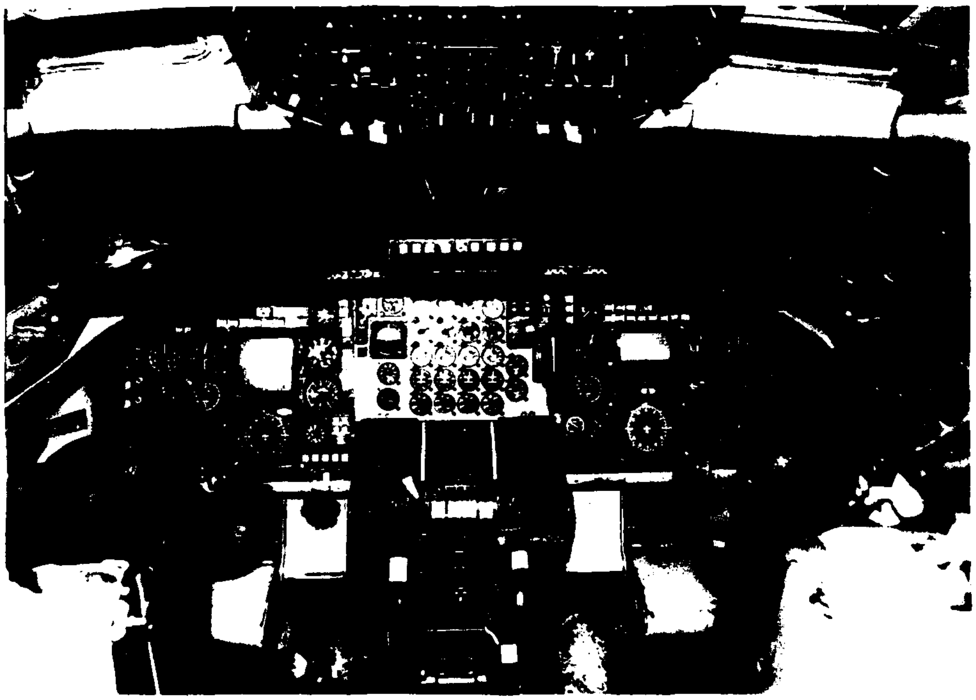

Figure 2. KC-135 simulator cockpit.

Computer Complex.

The simulator was connected to a series of large and small computer systems. This computer complex included five Gould series 32/7780, one Gould concept 32/8780, two PDP 11/34, three PDP 11/35, and several Silicon Graphics Iris Work Stations. The Silicon Graphics Work Stations were responsible for the EADI/EHSI visual presentations.

Experimenter's Console

The experimenter's console (Figure 3), also known as the Instructor-Operator Station (IOS), was located approximately 10 feet away from the simulator. It included a complete intercom system, with communication to and from the pilots inside the simulator. The console displays duplicated the simulator instruments and displays, and were used to monitor the pilots as well as the simulator performance . The experimenters were able to monitor the CDU, EHSI, and EADI of each pilot (P, CP) through repeater displays located at the IOS. Additionally, the IOS provided the experimenter, via a data display page (Table 1), with airspeed (indicated airspeed-IAS, true airspeed-TAS, and groundspeed-GS); altitude (Barometric-MSL and radar-AGL); heading (true-TH and magnetic-MH); present position; currently tuned radios (UHF1, UHF2, HF) and navigation aids (VOR1, VOR2, LOC1, LOC2, and TACAN); date and time; current waypoint information; current airport selected for the visual system; and the status of the gear, flaps, and boom. Furthermore, the console controls permitted the experimenter to start the simulation via the IOS set-up page (Table 2) and to terminate the mission via the IOS change modes page (Table 3). This page also allowed the experimenter to engage/disengage the boom and to address the data display page and two other IOS pages, the airport selection page and the malfunction selection page (discussed later).

Figure 3. Crew Station Evaluation Facility Experimenter's Console.

Table 1. An example of the data display page.

AIRSPEED	ALTITUDE	HEADING	DATE/TIME	MISC.
IAS 0	BARO 105	TRUE 000	01/01/01	GEAR UP
TAS 0	RALT 9	MAG 345	08:09	FLAPS 0
				BOOM DISENGAGED

RADIOS	TACAN	POSITION
UHF1 223.00	IDENTIFIER MHR	LAT N38-33.6.6
UHF2 227.00	RADIAL DME 000/ .0	LONG W121-17.0.0

DEST.INFO	DATA COLLECTION	SIMULATOR STATUS
WP# 0	MISSION MATHER AFB	FLYING
DIST .0	AIRPORT MATHER AFB	
TTG 0000	DATA INACTIVE	
CRS 000		
OFFST 10		

Press ATTENTION to EXIT PAGE

Table 2. An example of the IOS set-up page.

RECORD AMP RUNS

1. TRIAL #	: 4	A. INCREMENT RUN	: ON
2. SUBJECT #	: 14	B. DATA COLLECTION	: ON
3. MISSION	: CASTLE AFB	C. FILE NAME	: M003S14V01.D

PRESS 'R' TO RUN

ENTER COMMAND ('X' TO EXIT):

Table 3. An example of the change modes page.

IOS PAGE - CHANGE MODES

ENGAGE	- ENTER B
CHANGE AIRPORT	- ENTER C
SELECT MALFUNCTION	- ENTER M
RESUME MISSION	- ENTER R
TERMINATE MISSION	- ENTER X

PLEASE ENTER YOUR SELECTION

Experimental Design

The primary objective of the Test and Evaluation phase was to demonstrate the feasibility of the CSEF conceptual cockpit design. To accomplish this, 10 KC-135 operational aircrews from SAC air bases were required to fly four mission scenarios over a period of 5 days and 2 KC-10 aircrews were required to fly three mission scenarios over a 4-day period. Since the KC-10 crew had no navigator and only flew the Mather and Castle missions, this resulted in a repeated measures mixed design (3 Mission x 3 Position x 2 Plane). All missions were successfully completed. Based on initial direction by the system program office and SAC, several assumptions were made at the very beginning of the three-phase effort. These were:

1. The missions were unclassified training missions. Classified Command and Control Procedures were ignored.

2. All mode 1, 2, 3, and 4 settings were assumed to be set and correct. Except for the mode 3 setting, no actual setting of codes was performed by the crewmembers. The KIK-18 was simulated.

3. Celestial navigation was not required.

4. Global Positioning System (GPS) and associated satellites were available and used.

5. A dual Inertial Navigation System (INS) was available and used.

6. Current Federal Aviation Administration (FAA)/Air Force/Strategic Air Command regulations and directives were followed.

7. Crews were familiar with current mission planning software used on the Zenith Z-248.

Training Materials

The following materials were forwarded to the aircrews for study prior to their arrival at the Crew Station Evaluation Facility:

1. Programmed text describing the proposed design. It included detailed descriptions, standard operating procedures, and proposed use of the equipment to include illustrations of the Radar, Electronic Flight Instrument System (EFIS), Electronic Attitude Director Indicator (EADI), Inertial Navigation Systems, Control Display Unit (CDU), and Global Positioning System.

2. Abbreviated checklists were given to each crew member.

3. All routes of flights and associated mission paperwork were also provided to enable crew mission planning prior to the crew's arrival at the CSEF.

Procedure

Two aircrews (P, CP, N) were brought in for 1 week at a time. Approximately 1 week prior to the arrival of the aircrews, mission materials, training pamphlets, and checklists were forwarded to each crew for review and study. On the first day, each aircrew underwent training to familiarize them with the design and operating characteristics of the proposed system. Emphasis was placed on the crew understanding how to use the various subsystems, in addition to CDU page and radar scope interpretation. The following 4 days were used to fly each of the 4 mission scenarios (one a day).

Training

The first day of the week was designated as a training day for both crews. The crews initially received a standardized briefing covering (1) the purpose of the study, (2) the missions to be flown during the week, (3) safety procedures, (4) system descriptions/operations, and (5) their schedule for the week. Additionally, all of the pilots were required to perform a Subjective Workload Assessment Technique (SWAT) card sort (described later). Each crew was then trained on each of the newly introduced subsystems. They were also provided flight simulation time so that they would become accustomed to the actual flight characteristics/peculiarities of this simulator. CSEF personnel were present at all times to answer any questions.

Day 2 of the week long schedule required the crew to fly the training mission. The training mission provided the crew with experience in the normal use of the equipment and in the handling of various malfunctions. It also allowed the crews an opportunity to use the equipment in a similar manner as they would during actual flight, while providing the crew the opportunity to interact with the experimenter, thereby gaining increased understanding of the various pieces of equipment.

While the pilot and copilot were receiving training, the navigator was instructed on the role that he was to play in the study. The navigator acted as an impartial observer inside the cockpit. Since the navigator worked with the crew on a regular basis, his presence would not seem out of the ordinary; whereas, the presence of an experimenter might prove more intrusive. He was responsible for recording any checklist omissions or deviations made by the crew. The navigator was also encouraged to assist the crew on navigational concerns at any time during training. After the training period, the navigator provided no further assistance to the crew.

Upon completion of training, the crew was given mission materials for each of the 3 days. They were then required to conduct mission planning and prepare the associated paperwork for each mission. The crew was told the actual order of the missions they would fly during that week, but were not informed as to the difficulty level of each mission, nor were they informed as to the actual sequence of events. The crew was expected to have completed all mission paperwork prior to their arrival for the flight. At no time was the navigator to assist the pilot team (P, CP) in mission planning.

Mission Simulation

Flights

Each crew arrived at the CSEF each mission day and checked Notices to Airmen (NOTAMS), the schedule, and the Flight Crew Information File (FCIF). The crew arrived with all flight equipment that they ordinarily brought on a regular flight with the exception of their helmets and flight lunches. The crew received a weather briefing (weather sheets were developed by the Wright-Patterson AFB weather shop to enhance mission realism), cell briefing, and time hack prior to being forwarded to the simulator. At their discretion, the crew proceeded to the simulator to perform the necessary checklists for scheduled takeoff and flight.

Table 2 presents an example of the computer program page that the experimenter used to select the mission flown, the subject crew, and whether data were activated.

Additionally, an IOS set-up control interface program developed to simplify user-computer interaction allowed the experimenter to monitor real-time characteristics of the simulator as it flew each configuration (Table 1).

The crews were required to fly four different mission scenarios (KC-10 crews did not fly the Minot Mission). These missions were actual operational mission profiles flown at Minot AFB ND, Mather AFB CA, and Castle AFB CA and modified slightly for our simulation efforts. The missions averaged 3 hours in duration and varied in their degree of difficulty (easy, medium, and hard). The degree of difficulty was manipulated through the use of weather factors, maintenance problems, and mission requirement changes. Upon entering the simulator, the crew immediately began their Preflight/Before Takeoff checklists. The crews were required to remain in the cockpit from preflight through postflight. The order and time that each crew flew their 3 missions were counterbalanced for each mission (Minot , Mather, Castle) and for time of simulation (morning vs. afternoon).

Training Mission. The training mission was on day 2, the second day of training. The mission was a three-ship cell departure and join-up from Castle AFB, CA. The crew was number two. At takeoff (T.O.)+20 minutes, a cell lead change was performed and the test crew became lead. The tanker cell conducted an enroute rendezvous with a cell of F-16s at the Air Refueling Initiation Point (ARIP) for AR route 6B. The F-16s required 5,000 (5K) pounds more fuel than scheduled. The northern end of the AR route required the cell to deviate around thunderstorms. At the end of the refueling route, command post notified the test crew that they were being diverted to McChord AFB and were to await further instruction. Immediately after the crew broke up cell and began its alter heading to McChord, they experienced a generator failure and lost both INSs and GPS equipment. The crew was required to navigate to McChord and land the aircraft (Figure 4).

Minot Mission. This mission was the "easy" mission. The flight was a single ship mission departing from Minot AFB. The mission took off 9 minutes late. The receiver (one B-52) arrived at the AR route 106HW ARIP for an on-course rendezvous 3 minutes early. The AR off-load was 20K pounds more than scheduled. The crew experienced radio communication difficulties with Center, therefore, delaying End Air Refueling (EAR) clearances. Enroute to the Minot AFB Initial Approach Fix (IAF), the crew experienced a hydraulic failure (Figure 5).

Mather Mission. This was the "medium" difficulty mission. This mission was a two-ship cell departure with an 11-minute late takeoff from Mather AFB CA. At T.O.+10, Center directed the cell to turn left direct to the ARCP for their point parallel rendezvous with two B-52 bombers. At T.O.+1:15, INS drift was 5 NMPH when the crew experienced GPS failure. The crew performed weather avoidance due to thunderstorms on AR route 7B as required. Cell break-up occurred at EAR. At EAR, the crew received instructions via HF radio that they were diverted to Castle AFB for passenger ferry. The mission terminated with a landing at Castle AFB CA (Figure 6).

Castle Mission. This mission was labelled the "hard" mission. The crew was number two in a two-ship cell. The mission began at Castle AFB CA with an on-time takeoff. Immediately after takeoff, the crew experienced an autopilot malfunction. Cell break-up was scheduled at the Sacramento TACAN, prior to air refueling; however, the lead aircraft experienced hydraulic failure immediately after cell departure and join-up was performed. This left the crew as a single ship. At the Sacramento tacan, the crew was

Figure 4. Example of the Training mission route of flight.

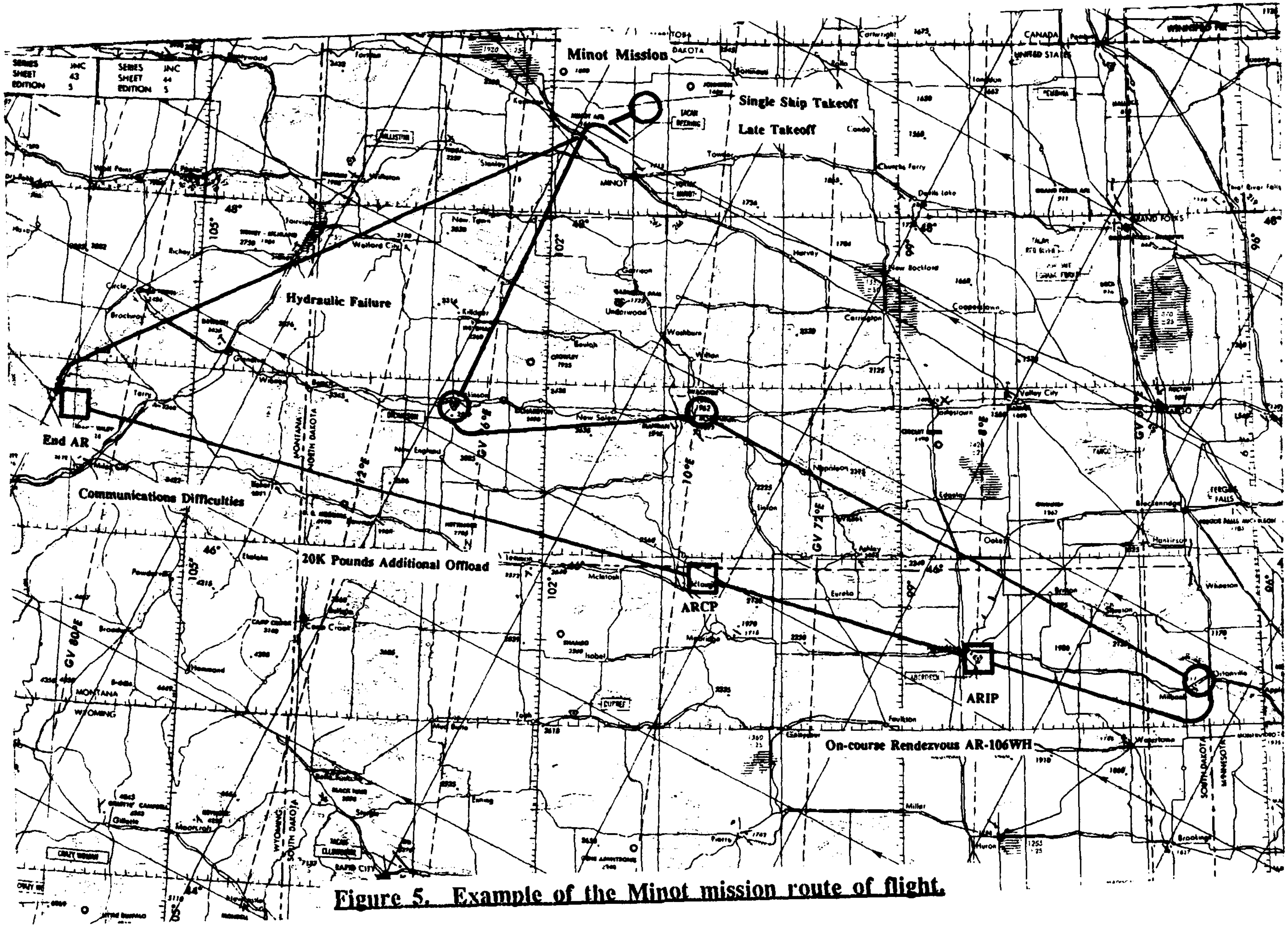

Figure 5. Example of the Minot mission route of flight.

Figure 6. Example of the Mather mission route of flight.

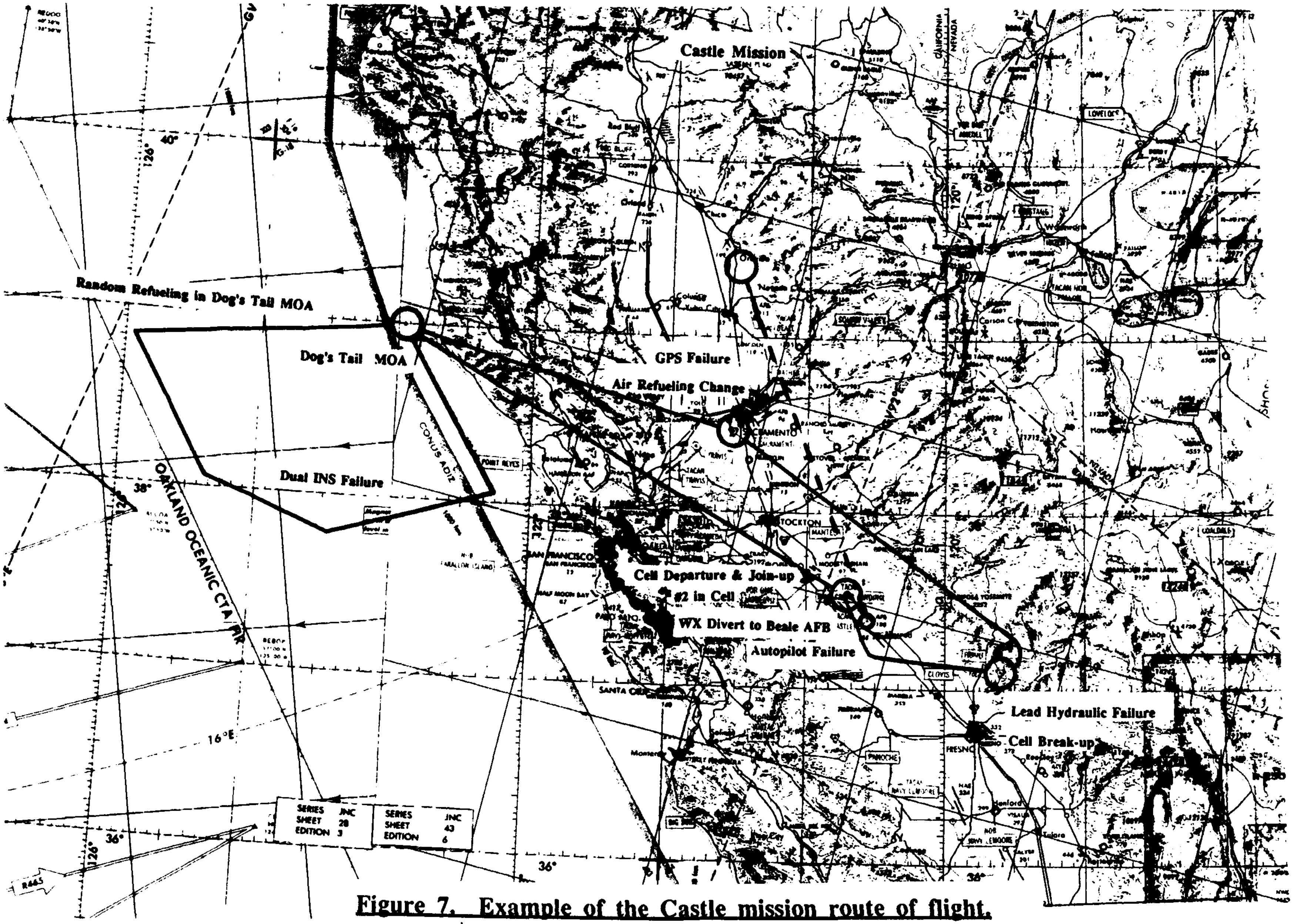

Figure 7. Example of the Castle mission route of flight.

informed that AR route 5WE was closed due to weather and that they would conduct random air refueling operations in the Dog's Tail Military Operating Area (MOA-W260) with a single F-16. Immediately after entry into Dog's Tail MOA, the crew experienced complete loss of both INSs, in addition to their GPS system. When the crew called for landing weather, they were given minimums that allowed for a precision approach to be flown. However, the crew never broke out of the weather and was forced to land at an alternate airfield of their choice. Throughout this mission the crew was required to deal with an increased volume of radio traffic and continuous deviations due to thunderstorms. (Figure 7).

Standardized mission scripts were provided to the experimenters to facilitate ease of communication and provide a timeline for the mission events. These scripts were developed in-house by a former SAC operational navigator and reviewed by current SAC operations personnel. The scripts provided the proper sequencing of events in addition to the precise terminology used by air traffic controllers, weather service personnel, operations personnel, maintenance personnel, and other aircrews. These scripts followed the actual flow of events and communications consistently across all missions and all crews.

The crew was required to make all radio calls and perform all actions that they would normally perform in actual flight. This included all start engines, taxi, takeoff, and cell formation calls. Additionally, the crew was required to clear any flight plan changes with Center. Since the crew did not follow scripts and was unaware of the events until actual occurrence, experimenters were trained to listen intently to all communications and respond appropriately. In an effort to enhance realism and to reduce the monotony that might ensue from hearing a single voice repeatedly, it was decided to use at least two experimenters. Consequently, two experimenters, at least one with operational flight experience, acted as air traffic controllers, command post personnel, boom operator, etc.

The experimenters started the simulation via the IOS set-up page (Table 2) when the crew arrived at the cockpit. Experimenters continually monitored the actual position and status of the aircraft via the data display page (Table 1). The experimenter changed the NVS airport visual database through the use of the airport selection page (Table 4). This allowed the console operator to change the NVS without the knowledge of the pilots. In addition, it allowed the mission to continue without interference.

Table 4. An example of the airport selection page.

IOS - AIRPORT SELECTION

SELECT TRAINING	-	ENTER 0
SELECT MINOT AFB	-	ENTER 1
SELECT MATHER AFB	-	ENTER 2
SELECT CASTLE AFB	-	ENTER 3
SELECT McCHORD AFB	-	ENTER 4
SELECT LOS ANGELES	-	ENTER 6
SELECT DAYTON	-	ENTER 7
SELECT SAN FRANCISCO	-	ENTER 8
SELECT BEALE AFB	-	ENTER 9

PLEASE ENTER YOUR SELECTION

PLEASE ENTER AN X TO EXIT PAGE

Some of the missions required the console operator to fail various systems onboard the aircraft simulator. These malfunctions were implemented via the malfunction selection page (Table 5). This capability allowed the experimenter to induce workload at a predesignated time, thereby, standardizing the mission profiles across crews.

Upon completion of the mission, the pilots gathered their gear and were lead to a debriefing room. At this time, the pilots first entered their SWORD ratings (explained in the data collection section) onto the mission specific SWORD data collection forms (Appendix A). They were then administered a mission specific questionnaire. After completion of the questionnaire by all the crewmembers, the navigator and the experimenter debriefed the pilots on any errors made, suggestions for improvements, and answered any questions they might have had. At the completion of the fourth mission on the last day, all the crewmembers were required to answer a system specific questionnaire. The pilots were then required to perform a final card SWAT sort.

Table 5. An example of the malfunction selection page.

SELECT LEFT HYDRAULIC OVERHEAT	- ENTER O	DISENGAGED
SELECT RIGHT HYDRAULIC OVERHEAT	- ENTER 1	DISENGAGED
SELECT LEFT SYSTEM PRESSURE	- ENTER 2	DISENGAGED
SELECT RIGHT SYSTEM PRESSURE	- ENTER 3	DISENGAGED
SELECT LEFT AUXILIARY PRESSURE	- ENTER 4	DISENGAGED
SELECT RIGHT AUXILIARY PRESSURE	- ENTER 5	DISENGAGED
SELECT LEFT HYDRAULIC PUMP INOP	- ENTER 6	DISENGAGED
SELECT RIGHT HYDRAULIC PUMP INOP	- ENTER 7	DISENGAGED
SELECT AUTOPILOT FAIL	- ENTER 8	ENGAGED
SELECT GPS FAIL	- ENTER 9	DISENGAGED
SELECT INS #1 FAIL	- ENTER A	DISENGAGED
SELECT INS #2 FAIL	- ENTER B	DISENGAGED
SELECT GENERATOR #2 FAIL	- ENTER C	DISENGAGED

PLEASE ENTER YOUR SELECTION

PLEASE ENTER AN X TO EXIT PAGE

Data Collection

Aircraft performance data collection was on a 1-Hz cycle. The following parameters (with acronyms) were collected continuously throughout flight:

1. Indicated Airspeed (IAS)
2. True Airspeed (TAS)
3. Groundspeed (GS)
4. True Course (TC)
5. True Heading (TH)
6. Magnetic Heading (MH)
7. Altitude (ALT)
8. Altitude Deviation (ALTDEV)
9. Roll Rate (ROLL)

10. Vertical Velocity (VVI)
11. Course Deviation (CD)
12. Latitude (LAT)
13. Longitude (LONG)
14. Time
15. Switch Hits/Keystrokes
16. Time each menu page displayed

The above raw data were put into a congregate database and various statistical analyses were conducted on these parameters to evaluate the measures of performance listed below.

Measures of Performance

1. Control Time/Time Over Steerpoint Deviations: Time difference in minutes and seconds from designated control times (e.g., T.O., ARCT, RZ CT) (Ref: 60-4, Volume IX) .

2. Control Point/Steerpoint Deviations: Actual distance left or right of course in tenths of miles at control point (e.g., ARCP, RZ PT) (Ref: SACR 60-4 Vol IX).

3. Airspeed Deviation: Root mean square of deviation from planned indicated airspeed for Air Refueling track (ARCP or Precontact, whichever is later, until 5 minutes before EAR) (Ref: SACR 60-4 Vol IX).

4. Altitude Deviation: Total deviation from flight planned altitude + or - 100 feet in total feet (Ref: SACR 60-4, Vol IX).

5. Weather Deviation: Minimum distance from thunderstorm in tenths of miles (Ref: AFR 60-16, SAC Sup 1).

Measures of Workload

Subjective Workload Assessment Technique (SWAT)

SWAT (Reid et al., 1989) provides a global measure of subjective workload. SWAT is divided into three factors: (1) Time load, (2) Mental effort load, and (3) Psychological stress load. Time load depends on the availability of spare time and the overlap of task activities. It is rated on a three-point scale from 1-Often have spare time to 3-Almost never have spare time. Mental effort load is an indicator of the amount of attention or mental tasks that are required to accomplish a task, independent of the number of subtasks or time limitations. It is rated on a three-point scale from 1-Very little conscious mental effort or concentration required to 3-Excessive mental effort and concentration are necessary. Psychological stress load refers to conditions that produce confusion, frustration, and/or anxiety during task performance and, therefore, make task accomplishment seem more difficult. It is rated on a three-point scale from 1-Little confusion, risk, frustration, or anxiety exists and can be easily accommodated, to 3-High to very intense stress due to confusion, frustration, or anxiety.

The SWAT technique was used to determine the workload of each crewmember throughout each of the missions. Pilots sorted 27 cards with various descriptive workload levels of the three factors (Time, Mental effort, and Psychological stress) into a lowest to highest workload arrangement. This card sort allowed the individual to show which factors were considered as more critical. The SWAT card sort is a conjoint measurement technique that is subsequently used to generate a 100-point interval scale. The results of the data can then be submitted for traditional statistical analysis. The crew members performed the initial card sort on the morning of the first day and immediately after the fourth mission on the last day. SWAT ratings were requested at various times during each flight from each of the pilots. At that time, the pilots would respond with a numerical rating (1, 2, or 3) for each of the factors. For example, if a pilot said his rating was 132 (one three two), it meant his time load rating was one, his mental effort load was three, and his psychological stress load was two. These ratings were recorded by the experimenter for later analysis.

Subjective WORkload Dominance (SWORD)

SWORD (Vidulich, 1991) uses a series of relative judgments comparing the relative workload of different task and mission segments in reference to the aircraft. The rater was presented with a rating sheet that listed all possible paired comparisons of the tasks (see example, Figure 8). One task appeared on the left side of the line, and another task appeared on the right. The rater then marked the "EQUAL" slot if both tasks inflicted identical levels of workload. If either task caused higher workload, the rater marked a slot closer to the dominant task. The greater the difference between the two tasks, the closer the mark was placed to the dominant (higher workload) task.

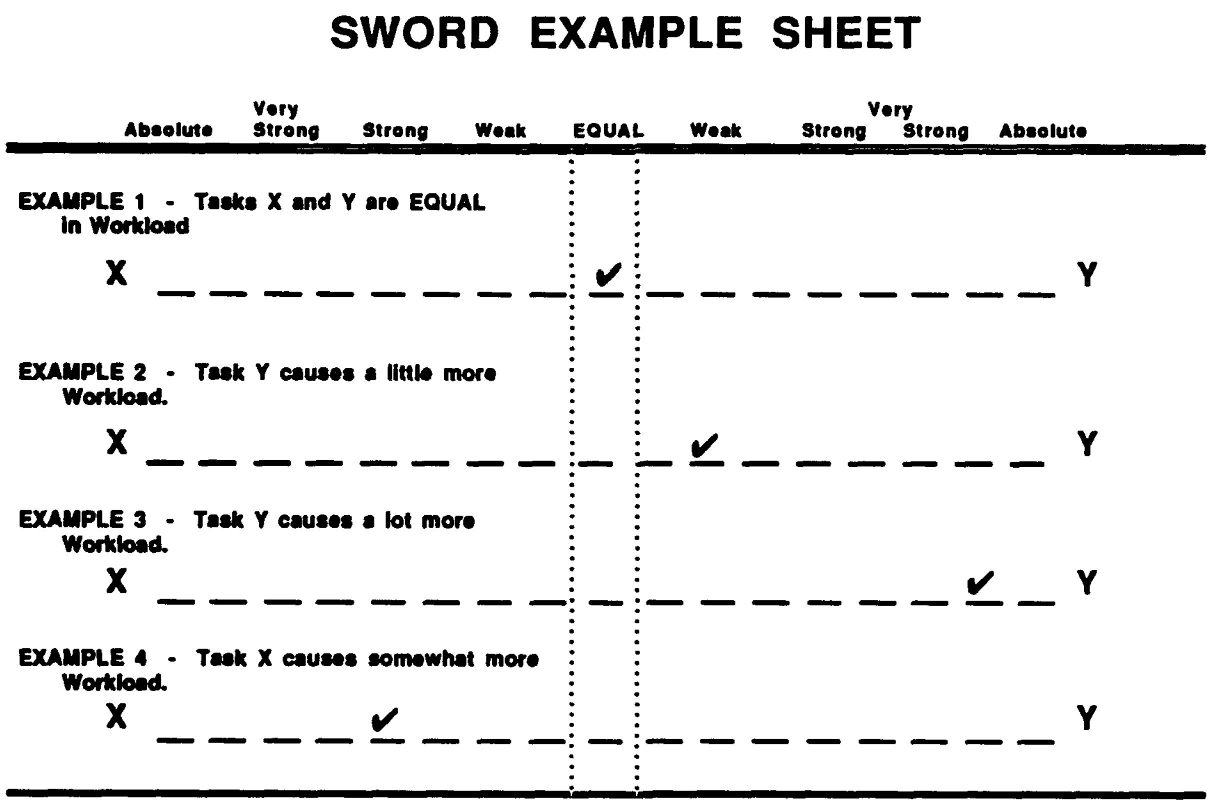

Figure 8. Instructional example for the SWORD rating technique.

Modified Cooper-Harper (MCH) Scale

The MCH scale (Figure 9) is a modified version of the original Cooper-Harper scale (Cooper & Harper, 1969). The MCH is a subjective measure of workload. The operator enters the decision tree at the bottom left and must make various decisions in arriving at his perceived workload. The MCH was given to the pilots via a mission questionnaire to determine their workload for various task requirements and again at the end of the study to determine their workload for the various mission segments as identified by Ward et al. (1991).

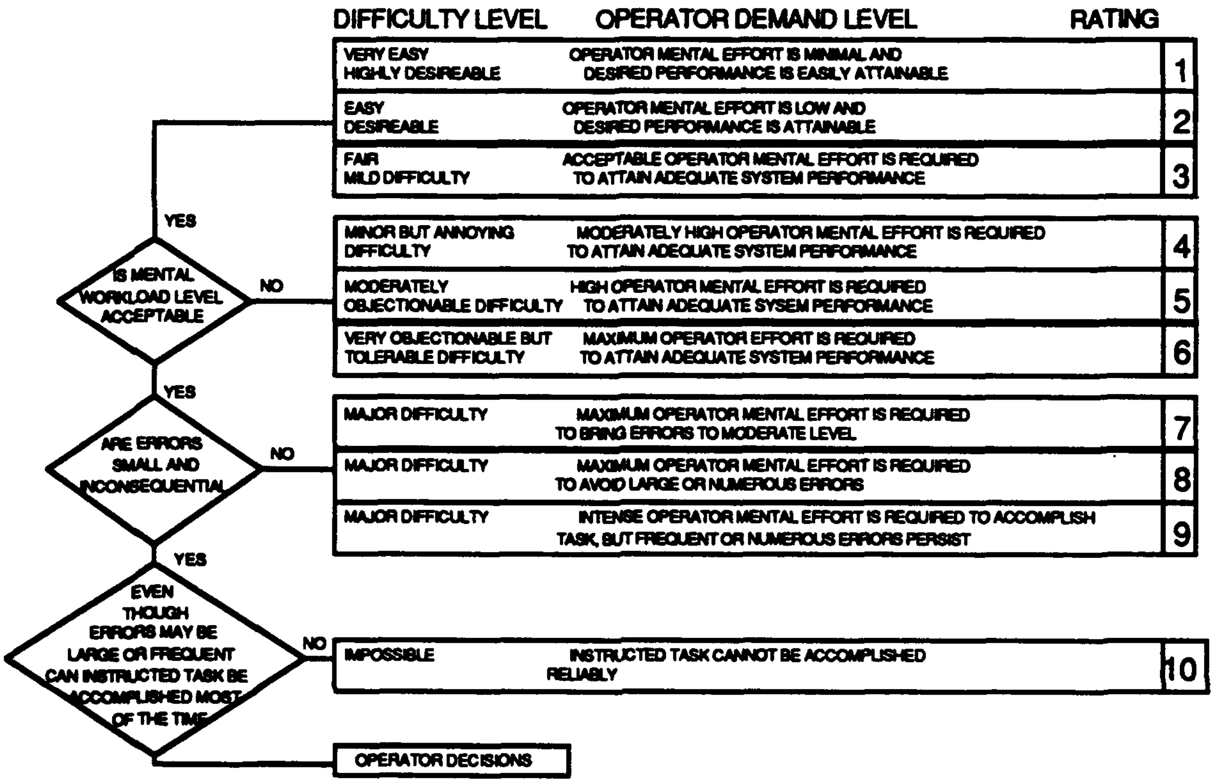

Figure 9. Decision tree for the Modified Cooper-Harper rating scale

Questionnaire Data

The crews were required to answer several questionnaires during the course of the experiment. A mission specific questionnaire (Appendices B-D) was administered to the crewmembers immediately following the mission. This questionnaire was used to specifically pinpoint high workload areas during the mission. Additionally, several identical questions were asked on each of the mission specific questionnaires to identify common high workload areas and also to serve as a mission difficulty manipulation check. On the final day of the study the crews were required to complete a 39-page system questionnaire (Appendix E). The questionnaire had 152 multiple choice items; each of which had a comments section allowing the crewmember to fully explain his answer. This questionnaire was designed to identify specific mission functional requirements necessary for successful mission accomplishment.

RESULTS AND DISCUSSION

This results section is broken up into four main sections. The first section analyzes the objective performance measures in order to evaluate whether the conceptual cockpit design would have met current Federal Aviation Agency, Air Force, and Strategic Air Command regulations and directives concerning mission performance. The second section, Mission Difficulty, explains the validity of our mission difficulty manipulations. The third section looks at the various subjective measures used in this study to determine the feasibility of the conceptual cockpit design and potential areas of concern. Finally, the system questionnaire data are discussed in detail. Each of the sections overlap to varying degrees as many of the measures allowed the authors to draw conclusions to different questions. The first three sections address the question, "Is it feasible to eliminate the navigator from the KC-135 cockpit." The final section identifies the minimum functional requirements necessary for the elimination of the navigator to be feasible.

Throughout the four sections, the reader will be presented multiple figures for both the KC-135 results and the KC-10 results. SWAT and SWORD figures represent the overall group rating, unless otherwise stated. Figures whose title begin with "KC-135" represent the overall group rating for both the KC-135 pilots and copilots combined. Figure titles beginning with "KC-10" represent the overall rating for both the KC-10 pilots and copilots combined. The KC-135 and KC-10 sample sizes were 20 and 4, respectively.

The various groups of interest are noted in the legend at the top of each figure. The "Pilot" group refers to KC-135 pilots/aircraft commanders only. The "Copilot" and "Navigator" groups refer to the KC-135 copilots and navigators, respectively. The "KC-10" group included both KC-10 pilots and copilots. The sample size (n) for each group, unless specifically noted otherwise, follows: Pilots (n=10); Copilots (n=10); Navigators (n=10); and KC-10 (n=4). Consequently, statistical analysis of the KC-10 data was not possible. Rather, KC-10 data are presented as a supplement to the KC-135 results and provide valuable trend information.

Objective Measures

Data collected on a 1-Hz cycle for each of the three missions were reduced and organized into five Measures of Performance categories: (1) Control Time Over Steerpoint Deviations, (2) Control Point/Steerpoint Deviations, (3) Airspeed Deviation (4) Altitude Deviation, and (5)Weather Deviation. These categories were then evaluated against Strategic Air Command Regulations SACR 60-4, Vol. I; SACR 60-4, Vol. IV; and Air Force Regulation AFR 60-16, SAC Supplement 1. Additionally, recorded comments from the navigator observers and the experimenters were used to supplement the data. The results of such an analysis are presented by category.

Control Time Over Steerpoint Deviations

The control time over steerpoint deviation was evaluated against the actual scheduled Rendezvous (RZ) time/Air Refueling Control Time (Time) for each mission. SACR 60-4, Vol. I dictates that all timing control points be made within +/-3 minutes. A review of the recorded data indicated that all actual control times (a total of 34) met SACR 60-4 requirements. No control time difficulties were recognized by the observer or the experimenter.

Control Point/Steerpoint Deviations

Course deviations are not to exceed 10 NM on either side of track in accordance with SACR 60-4, Vol. IV. Course deviation was evaluated throughout flight with increased emphasis placed on the period 5 minutes before air refueling to 10 minutes after rendezvous completion. No course deviation exceeded 10 NM from track with the exception of those required to avoid thunderstorms. All of these deviations were coordinated and approved by Center. No course deviations beyond ten miles were identified by either the navigator observer or the experimenter.

Airspeed Deviation

Since airspeed is a primary method for time control, airspeed deviation was evaluated during the air refueling portion of flight. It is during this time period that the tanker pilots must maintain a set airspeed. SACR 60-4, Vol. IV states airspeed must be within +/-10 knots for full qualification. In a review of the data, less than 1% of all data points exceeded 10 knots. Of the data points that did not meet the criteria, all were associated with the avoidance of the weather and the effort to maintain end air refueling timing considered as acceptable deviations.

Altitude Deviation

SACR 60-4, Vol IV requires that aircraft altitude be maintained within +/-150 feet of assigned altitude. Since crewmembers can and often did request altitudes other than those originally planned, increased importance was placed upon the observer and experimenter notes to derive actual altitude deviations. Additionally, altitude during the air refueling segment of the mission (which was consistent across crews) was used as baseline for determining altitude deviations. In a review of the data, only three altitude deviations exceeded the 150 feet criteria. Only one of the three deviations exceeded 500 feet. All of the deviations were momentary and corrective action was initiated by the pilots without outside intervention.

Weather Deviation

AFR 60-16, SAC Sup 1 imposes minimum distance criteria for thunderstorm avoidance. Specifically, thunderstorms must be avoided by 20 NM at or above FL 230 and by 10 NM below FL 230. Thunderstorm avoidance was evaluated throughout the entire mission. No crew had any difficulty in avoiding thunderstorm by the prescribed distance.

Of the five performance measures, only the altitude deviation category resulted in less than qualified activity, although momentary in nature. Crews indicated that an altitude warning signal that notifies a crew when they have gone beyond an assigned altitude (a role previously performed by the navigator) would all but eliminate this potential problem. The above performance measure results indicate that a two-person (no-nav) conceptual cockpit design can result in qualified activity and successful mission performance.

Mission Difficulty

The three missions (Minot, Mather, and Castle) were planned with varying degrees of difficulty based on the following factors: (1) Takeoff time, (2) Cell procedures, (3) Inflight replanning, (4) Weather, and (5) System/equipment malfunctions. The various mission difficulties were: (1) Easy (Minot), (2) Medium (Mather), and (3) Hard (Castle). Figure 10 shows the SWAT ratings provided by the KC-135 crews. Figure 11 is the SWAT ratings graph for the KC-10 aircrews.

The x-axis lists the missions flown by each of the KC-135 aircrews (Figure 10) and KC-10 aircrews (Figure 11). The y-axis represents an interval scale indicating the overall rating of the group for each of the missions. The higher the rating, the higher the perceived workload. The dashed line between points is provided as a visual aid in determining trend information between missions. As seen in Figures 10 and 11, mission difficulty as indicated by overall SWAT workload did increase from the Minot to the Mather mission and from the Mather mission to the Castle mission as predicted. This effect was statistically significant, $F(2, 51) = 7.29$, $p<.01$.

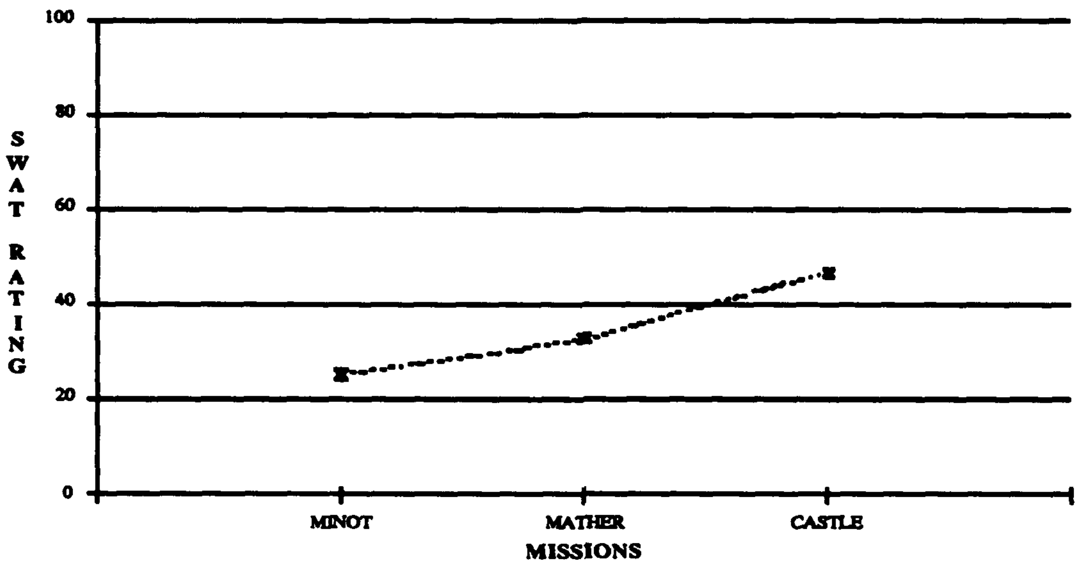

Figure 10. KC-135 Overall SWAT workload rating graph.

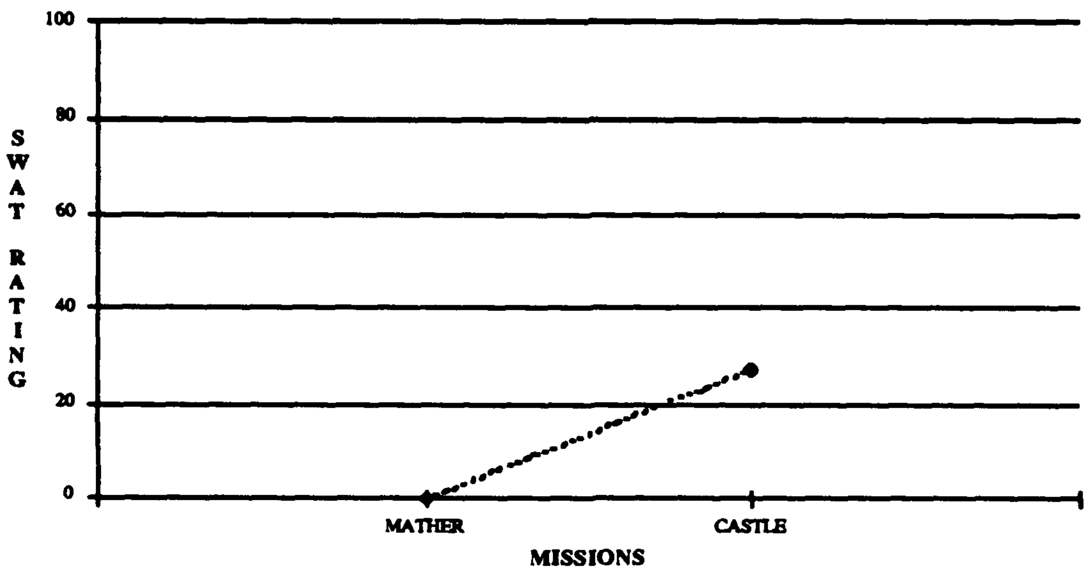

Figure 11. KC-10 Overall SWAT workload rating graph.

Additionally, crewmembers were asked to choose the adjective (easy, medium, hard) that best describes the difficulty of the mission just flown. The adjectives were later assigned a value of one for easy, two for medium, and three for hard. The subject group for Figure 12 consisted of all the KC-135 pilots, copilots, and navigators for each of the three missions (n=90). As seen in Figure 12, the missions were increasingly more difficult in the hypothesized direction. A two-way (mission x position) analysis of variance (ANOVA) of these responses resulted in a significant main effect for mission ($F(2, 87) = 35.07$, $p<.01$), but not for position. There was no interaction. This indicates that mission difficulty was the result of the mission manipulations and were in the hypothesized direction.

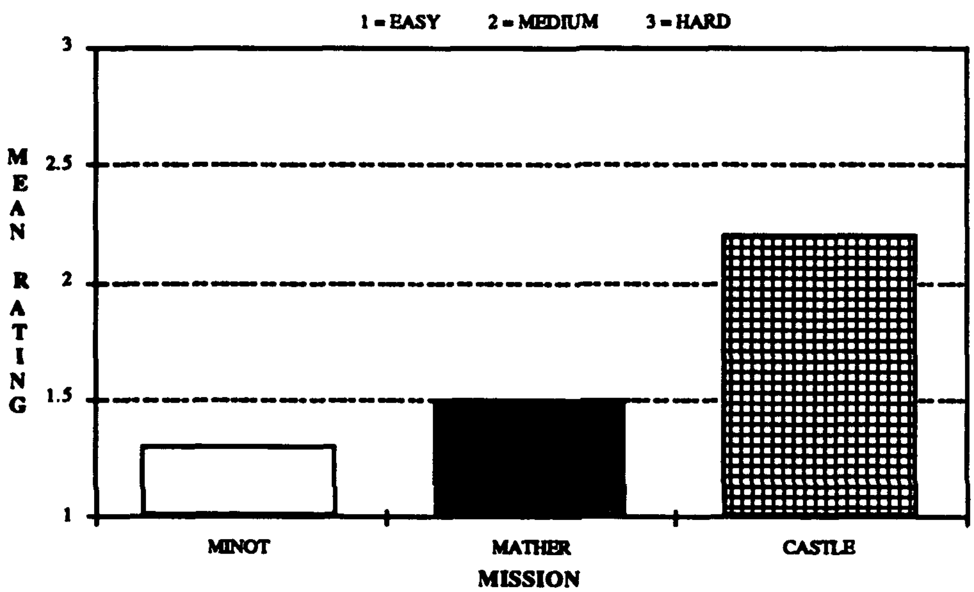

Figure 12. Adjective workload rating for each mission.

Crewmembers were also asked to rate each of the missions using the Modified Cooper-Harper (MCH) scale (Figure 9). Figure 13 shows the results of that rating process. The x-axis lists the three missions flown by the KC-135 aircrews. The y-axis represents an interval scale of the mean rating for that mission. A rating of 1 represents little workload; whereas, a rating of 10 indicates an excessive workload level. The figure shows the Minot and Mather missions were not different; but both were significantly different from the Castle mission, $F(2, 83) = 7.79$, $p<.01$. Additionally, a two-way ANOVA resulted in a significant main effect ($F(2, 83) = 7.79$, $p<.01$) for mission difficulty, but there was no main effect for crew position and there was no interaction effect. This again indicates mission difficulty was the result of the mission manipulations.

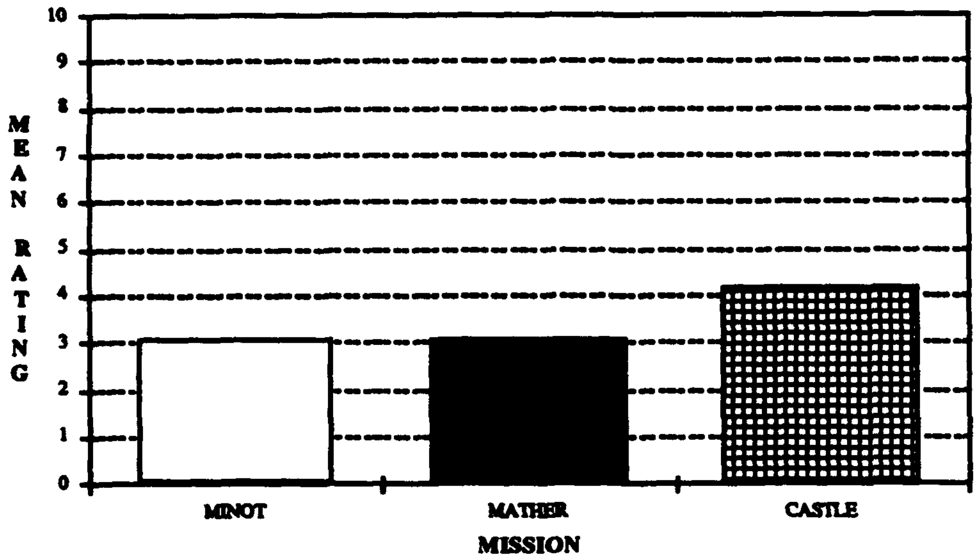

Figure 13. Modified Cooper-Harper workload rating for each mission.

The general trend of the data follows the expected pattern of results. Mission difficulty increased from the Minot mission to the Mather mission to the Castle mission. However, the increase in difficulty between the Minot and Mather missions was not always significant and, as shown in Figure 13, was sometimes minimal. This is a consequence of a last minute mission profile change. The Minot mission was originally planned with no hydraulic malfunction, but in order to evaluate the potential workload increase of such an event, it was added on. The Mather mission was originally considered for such an event, but it was felt that such an event would have increased the workload level to that of the Castle mission.

Given a preliminary analysis indicated the Minot and Mather missions were not significantly different from each other on the MCH, KC-10 crewmembers were only required to fly the Mather and Castle missions for the data collection portion of the experiment. The Mather mission was chosen over the Minot mission as it was the only mission requiring the crew to perform a point parallel rendezvous. This allowed for a comparison of the KC-135 and KC-10 data for both types of the air refueling rendezvous.

In summary, the increase in mission difficulty from the Minot mission to the Mather mission to the Castle mission was as expected and proved the manipulation of the mission difficulty was successful. Additionally, the missions flown represented a wide range of workloads and were representative of current operational missions flown today. Accordingly, the confidence in which we make the following conclusions is greatly increased.

Subjective Measures

SWAT

As mentioned previously, SWAT provides a subjective global assessment of workload. A review of Figure 10 shows the crewmembers did experience increasing mission difficulty as indicated by their overall SWAT rating for each of the missions. This provided the basis for determining the validity of our mission difficulty manipulations. SWAT can also provide the basis for identifying specific events during the mission and their associated workloads. This was accomplished by identifying specific events (events believed to be associated with higher workloads) within each of the missions prior to the study. Then, at designated times during the mission, the experimenter requested a SWAT score for each of the events. These scores were then placed into the database and workload scores were determined. These workload scores were then averaged and the resulting graphs were developed.

Figures 14-18 allow for the analysis of each mission for each of the specific events. Unlike Figures 10 and 11, the x-axis lists the specific mission events rather than the missions flown. The y-axis is the same as Figures 10 and 11 and represents the mean rating of the group for each of the mission events. The higher the rating, the higher the perceived workload. The dashed line between points is again only provided as a visual aid in determining trend information between the missions events. Reid and his associates (G. B. Reid, personal communication, March 4, 1991) at the Armstrong Laboratory are currently working on determining the SWAT score for workloads associated with moderate effort levels (areas of concern). Initial results indicate that such a score will fall between 40 and 50. Therefore, for purposes of this study, events with a SWAT workload rating above 40 are identified as an area of concern.

Figure 14 presents the SWAT ratings for the three Minot mission events: (1) Late takeoff, (2) Air refueling, and (3) Hydraulic malfunction. Figures 15 and 16 present the the KC-135 crew and the KC-10 crew SWAT ratings for the three Mather mission events: (1) Late takeoff/Cell, (2) WX avoidance, and (3) Replan. Figures 17 and 18 are the respective SWAT ratings for the Castle mission events: (1) Cell, (2) Replan, (3) Random Refuel, and (4) WX Divert/Missed App.

Late takeoff covers the late takeoff the crew encountered, coordination with Center, and the inflight replanning needed to regain scheduled mission timing. *Cell* events included the cell departure and join-up phase of flight, cell position changes, and associated communications. The *air refueling/random refuel* event included the on-course or point parallel rendezvous, fuel transfer via the fuel management panel, the termination of the refueling, and all associated radio communications. *WX avoidance* required the identification and avoidance of thunderstorms, in addition to Center coordination of any route deviations/changes. *Replan* events covered navigation route changes, timing changes, and the associated coordination with Center. The *hydraulic malfunction* event covered the malfunction, all communications, and the approach and landing. The *Wx divert /missed approach* event was based on the the crew's approach into Castle, the missed approach procedure, inflight replanning to Beale, and all associated communications.

A review of Figure 14 reveals that none of the Minot mission events received a rating over 40 by the KC-135 pilots/copilots. This indicates an "easy " mission such as this one would result in workloads that are manageable, given the CSEF conceptual cockpit design. Similarly, the KC-135 pilots/copilots considered the workloads for the Mather mission events (late takeoff/cell weather avoidance and replan) as manageable, although slightly higher than the Minot events (Figure 15). Minot mean rating was 25.29 and the Mather mean rating equalled 32.68. KC-10 crews reported workloads associated with the Mather mission events as very low (Figure 16), despite the fact that they were not qualified in the KC-135. This was attributed to differences in experience and training. Specifically, KC-10 pilots/copilots are trained in navigation and radar procedures. They are the navigator on the aircraft and currently fly with a cockpit similar to the CSEF conceptual cockpit design. The results presented in Figure 16 may represent the effects of increased training.

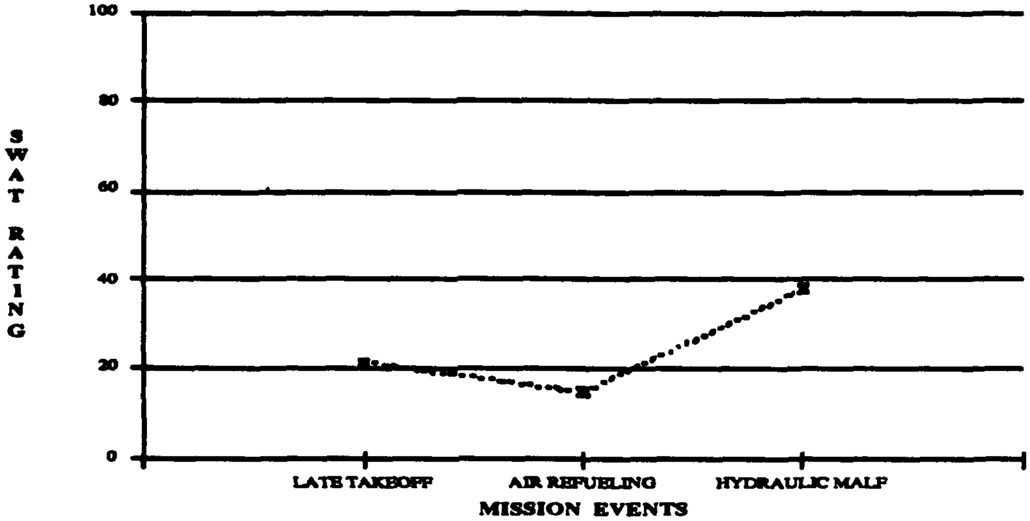

Figure 14. Minot SWAT rating for various mission events.

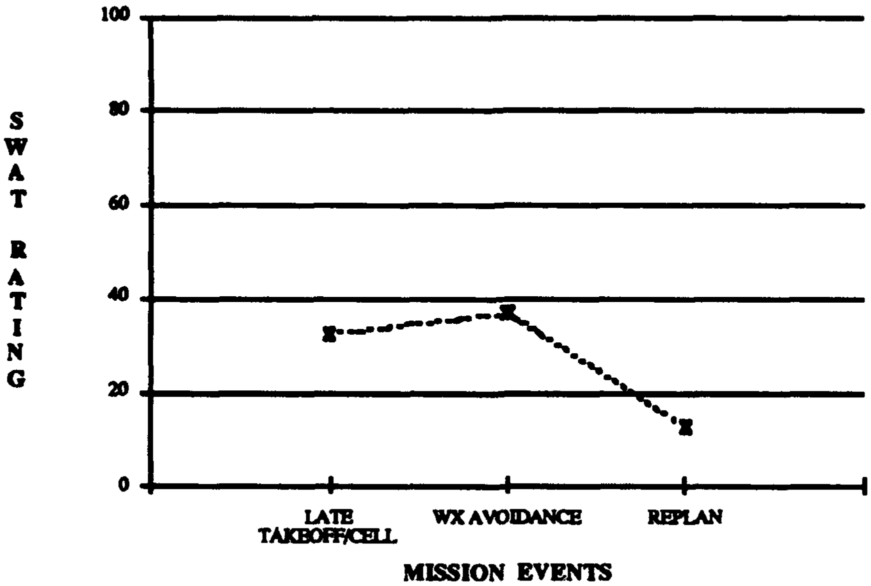

Figure 15. KC-135 Mather SWAT rating for various mission events.

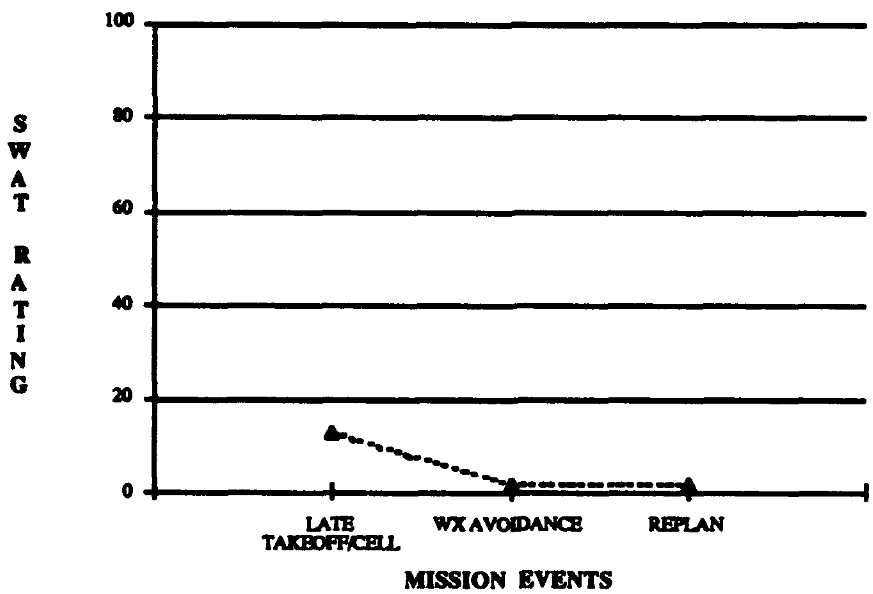

Figure 16. KC-10 Mather SWAT rating for various mission events.

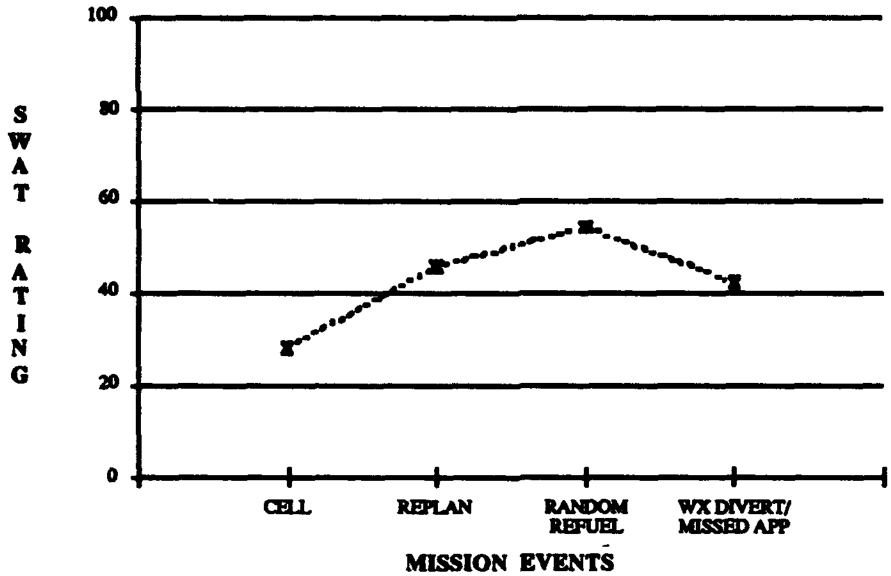

Figure 17. KC-135 Castle SWAT rating for various mission events.

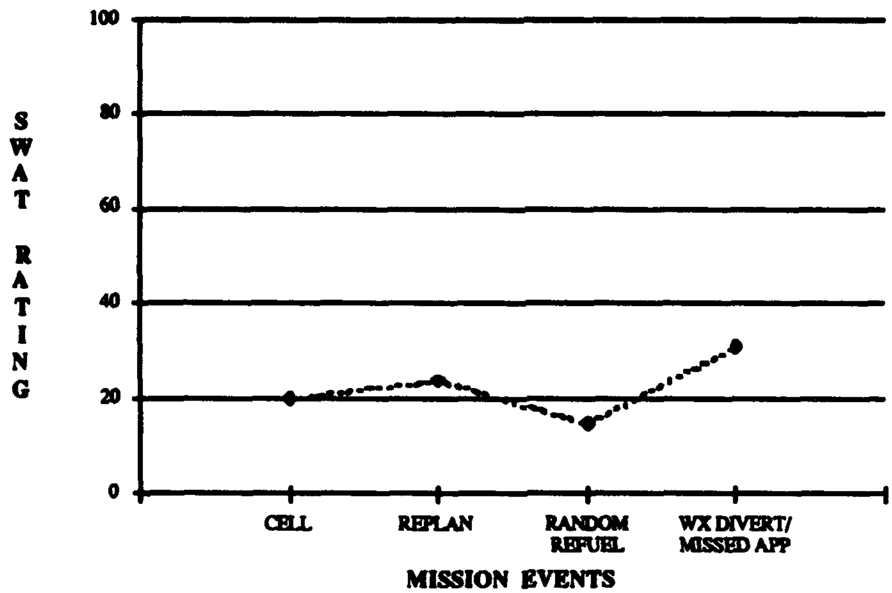

Figure 18. KC-10 Castle SWAT rating for various mission events.

Figure 17 reveals three of the four Castle events as potential areas of concern for KC-135 pilots. The replan, random refuel, and WX divert/missed approach events all had SWAT ratings exceeding the 40 chosen as our area of concern. This mission was intentionally designed to drive workloads above the redline value of 40 in order to evaluate potential system design problems (discussed in the questionnaire section). In discussions and inquiries into the difficulties involved with these areas of flight, KC-135 pilots/copilots felt training in navigation procedures was insufficient. They also felt that the requirement to fly the airplane full time due to the autopilot failure was definitely a workload producer.

In contrast, KC-10 pilots/copilots did not experience the same workloads as that experienced by the KC-135 crewmembers. Due to inadequate KC-10 sample size, statistical testing was not feasible. Figure 18 shows the KC-10 crewmembers' workload rating for the three areas of concern were all under the hypothetical "red line" of 40. This is attributed to a large degree to the increased training the KC-10 crewmembers receive in similar flight systems and navigational procedures. KC-10 crewmembers stated that their workloads were more the result of having to fly the plane continuously throughout flight and being unqualified in the plane.

As a result of the SWAT global assessment of the crewmembers workloads, further explanation as to what specifically was the source of the higher workloads associated with the three areas of concern was needed. Identification of the specific tasks causing higher workloads would aid engineers in developing the necessary functional requirements for successful mission accomplishment. The ability to identify specific tasks within the potential areas of concern was the reason for collecting SWORD data during the experiment.

SWORD

The Subjective Workload Dominance technique uses a series of relative judgments comparing the relative workload of different tasks and mission segments in reference to the aircraft. Such a comparison provides valuable information as to whether one task is believed to cause more workload than another task. It also provides an indication of which system (aircraft vs. simulator) resulted in higher degrees of workload.

SWORD data were collected for three mission segments for each of the three missions. The mission segments chosen for each of the Minot, Mather, and Castle missions were determined prior to data collection, based on those three segments hypothesized to be associated with higher workload levels. The tasks selected for a given mission segment were based on (1) tasks believed to be performed most often and (2) the task anticipated level of difficulty. These determinations were a direct result of the function analysis previously performed by Ward et al. (1991).

To aid in the understanding of the results, a detailed explanation of Figure 19 is provided. Figure 19 presents the results from the cruise segment of the Minot mission. The x-axis represents the particular tasks of interest for the chosen mission segment. The y-axis is an interval scale used to indicate the relative relationship between the aircraft and the simulator for a given task. The asterisk indicates the relative workload associated with a given task in the simulator (i.e., CSEF conceptual cockpit design with no navigator); the square indicates the aircraft (i.e., current model aircraft with a navigator). The lines between asterisks and between squares provide trend information. Subsequent figures (Figures 20-26) are presented using the same scale graph. The particular mission, mission segment, aircraft, and tasks vary from one figure to the next. Additionally, similar figures for the KC-10 crewmembers are directly below those of the KC-135 to aid in the comparison between the two aircraft.

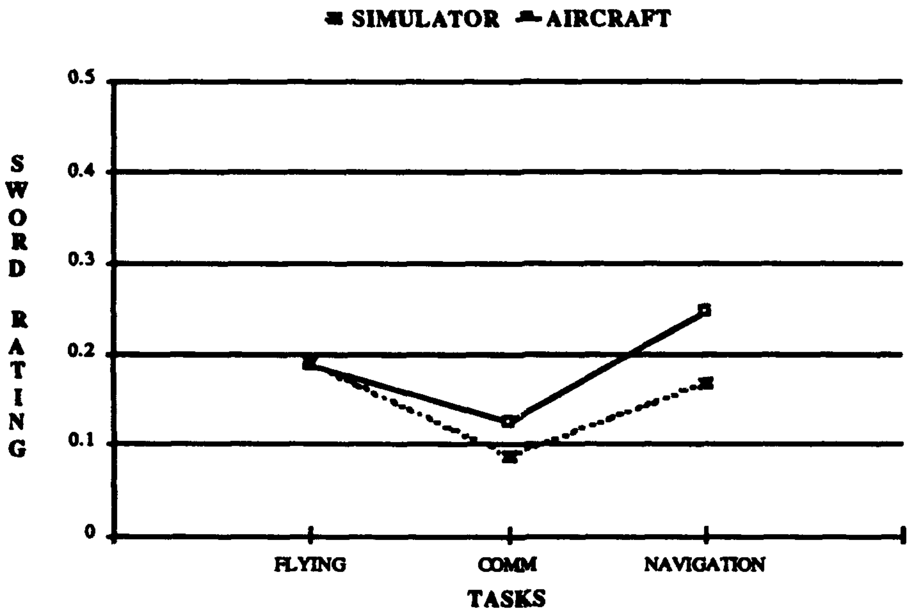

Figure 19. Minot SWORD ratings for the cruise segment.

Figure 19 provides the results for the cruise segment of the Minot mission. The three tasks compared during this segment were the flying task, the communications task, and the navigation task. The flying task was based on the level of difficulty for maintaining airspeed, altitude, and heading. The communications task involved all communications with Center and the receiver aircraft, the selection of assigned radio frequencies, and the control of the UHF and HF radios. The navigation task involved all activities to ensure route timing and course control were met.

A review of Figure 19 reveals the cruise segment was believed to be lower in workload for the CSEF conceptual cockpit design than for the current aircraft, although not statistically significant. Only the flying task was rated slightly higher for the simulator than for the aircraft, although the two were not statistically different from each other. These results indicate that, for the cruise portion of flight, the CSEF conceptual cockpit design resulted in workloads that were not any higher than that of the current aircraft.

Figure 20 indicates that, except for the flying task (Maintaining LOC/GS), the simulator was again rated as lower (but not significantly) in workload relative to the crewmember's current aircraft for the approach and landing segment of the Minot mission. As before, the simulator was rated as slightly higher in workload for the flying task, but once again was not statistically different from that of the aircraft. A trend of higher workloads for flying the simulator is already obvious at this point. The remaining figures (Figures 21-26) also indicate that flying the simulator was rated as more difficult (higher workload) than flying the reference aircraft for both the KC-135 and KC-10 pilots. When questioned why they felt the simulator was harder to fly, the crewmembers responded that "*all* " simulators are harder to fly than the actual aircraft. They stated the control loads and trim capabilities of this and other simulators are not as realistic as the actual plane and, therefore, increase the difficulty of keeping the aircraft properly trimmed for level flight. However, when asked how this simulator compared to other training simulators, the pilots felt the simulator was a good simulator. One subject even stated that it was the best (most realistic) KC-135 simulator he had ever flown.

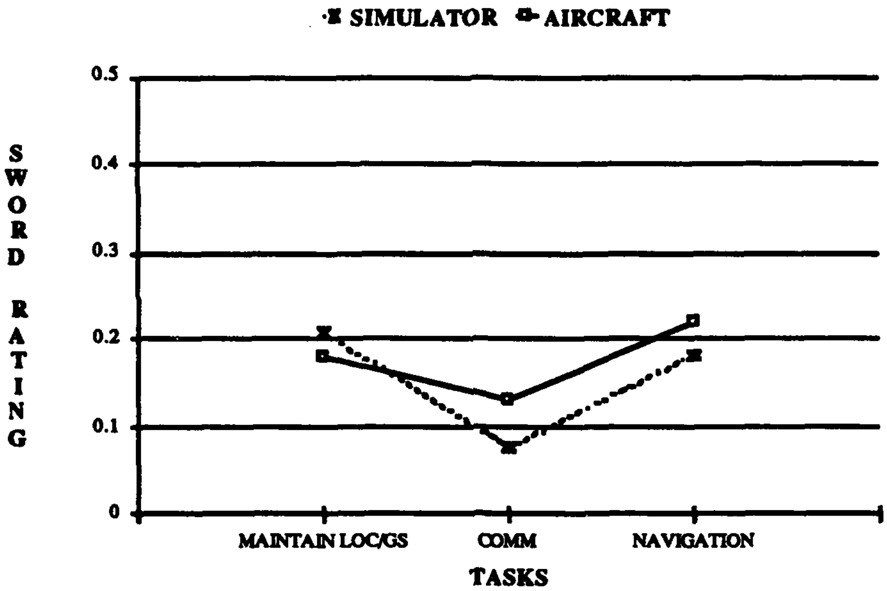

Figure 20. Minot SWORD ratings for the approach and landing segment.

Figures 21 and 22 are the graphed results of the Air Refueling segment for each mission. The fueling (FUEL) task involved the management of the Fuel Management Panel (FMP), transfer of fuel, maintenance of the proper center of gravity (Cg), and the monitoring of fuel flows. The communications task and the flying tasks were similar to those explained previously. The KC-135 graph (Figure 21) shows that only the flying portion of the air refueling segment was considered as more difficult in the simulator $F(2, 117) = 7.94$, $p<.01$. The pilots again attributed this increase to the idea that all simulators are more difficult to fly than an actual aircraft. This effect was even more noticeable for the Castle mission, $t(38) = 3.8153$, $p<.01$. This is the result of the increased "hands-on" flying time that resulted from the autopilot failure experienced during the Castle mission. No significant effects were found between the reference aircraft and the simulator for the communications or fueling task.

Figure 22 reveals KC-10 pilots reported higher workloads in the simulator than the aircraft for each task during the air refueling portion of the missions. An initial reaction to this situation might be to find the conceptual cockpit design as flawed, but further investigation uncovered this apparent discrepancy to be the result of the differences between the two aircraft. Only the fueling and flying tasks resulted in differences greater than 0.1, indicating the tasks might be significant given a larger sample size. The flying difficulties are due to two reasons. The first reason is that the pilots were not qualified in the KC-135 and, therefore, their reference aircraft (KC-10) would be, by default, easier to fly. The second is again attributed to the increased difficulty associated with flying a simulator as compared to an actual aircraft. The fueling task may be the result of the KC-10 crew duties. The KC-10 has a flight engineer onboard the aircraft who is responsible for the fuel management and the weight and balance of the aircraft. KC-10 pilots are not responsible for any of the fueling task (as previously defined) on board the KC-10. Accordingly, the fuel tasking rating was extremely low (0.03) for the aircraft while the fuel rating for the simulator was substantially higher (1.6-2.0). An inspection of the communication tasks shows slight differences in workload between the simulator and the aircraft for the Mather mission and no difference in workload for the Castle. This indicates the communication task does not substantially increase workload during the air refueling

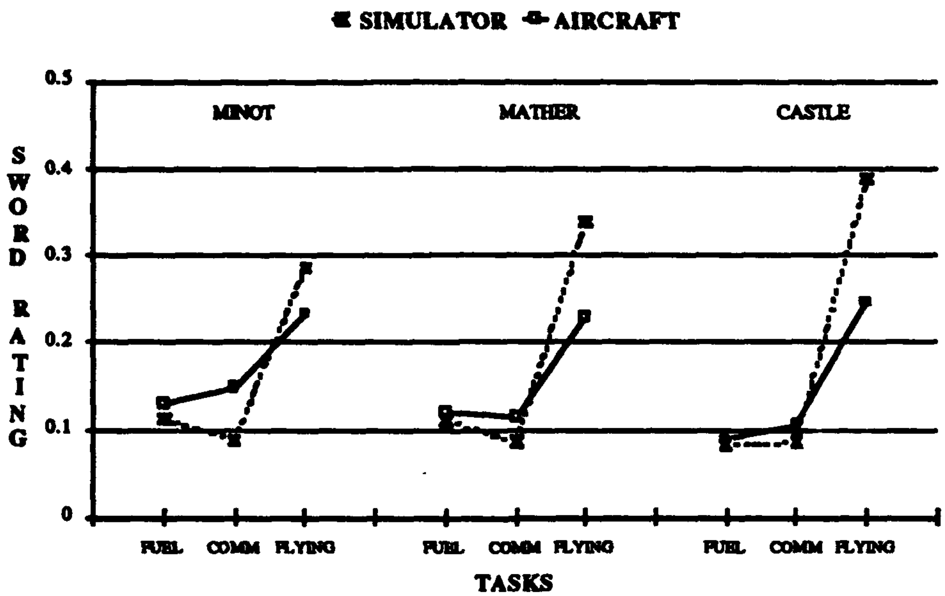

Figure 21. KC-135 SWORD ratings for the air refueling segment.

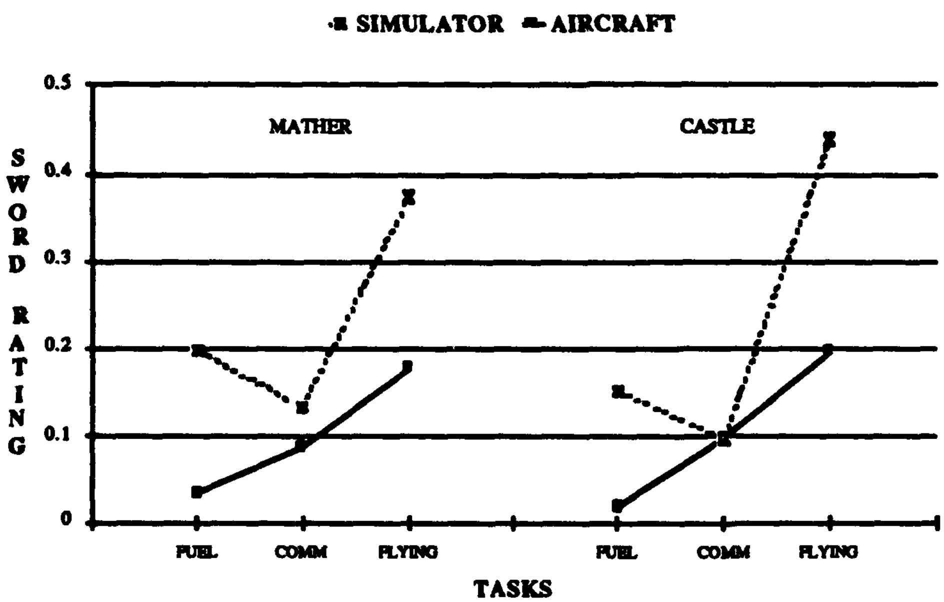

Figure 22. KC-10 SWORD ratings for the air refueling segment.

segment of flight. The reader must also remember that KC-10 data are based on a sample size of four. Such a small sample size for the KC-10 data makes statistical significance improbable. However, the trend information provides valuable information concerning potential areas of concern.

Figures 23 and 24 are the results of the cell departure and join-up segment of the Mather and Castle missions. The radar task involved the tuning of the radar set, radar scope interpretation, and scale selection to effectively perform a cell departure and join-up via radar means. The other two tasks were explained previously. Once again, only the flying task was rated as significantly higher workload in the simulator than in the aircraft, $F(2, 38) = 3.98$, $p<.01$, but only for the Castle mission. This may be attributed to the autopilot failure, which required an increase in manual flight by the crew. The remaining comparisons resulted in no significant differences between the aircraft and the simulator. This further supports the idea that this conceptual cockpit design did not significantly increase mission workload.

Figures 25 and 26 indicate the workload ratings for the weather divert portion of flight. Weather divert segment of the mission involved the avoidance of thunderstorms throughout the course and the ensuing coordination with Center. The storm avoidance task evaluated the capability to identify the weather on radar and the tuning of the radar. The inflight replan task required the pilot to determine his best route of flight to avoid the thunderstorm and the use of the mission management system to make that determination. The communications task was described earlier. For both the KC-135 and the KC-10, the pilots generally rated workload during the weather divert segment of the mission as lower for the simulator than for the aircraft.

Generally speaking, the SWORD results indicate workload was not any higher for the simulator than for the aircraft. The two exceptions to this statement were the actual flying capabilities of the simulator and the air refueling segment for the KC-10 pilots. The pilots unanimously stated that the major workload inducer during the flying task was the fact the simulator could not be trimmed as well as the aircraft. The increased workload encountered by the KC-10 pilots for the fueling task during the air refueling segment may be the direct result of the lack of a flight engineer. Since a flight engineer is responsible for the fuel task in the KC-10, it follows the KC-10 pilots would see their performance on this task in the simulator to be higher workload than the aircraft. The most important point to be made about the SWORD results is that relative workloads in the conceptual cockpit designed simulator were not higher than those currently believed to occur in the aircraft, despite the fact that the navigator was eliminated from the crew. This finding by itself is significant, since its supports the feasibility of such an endeavor.

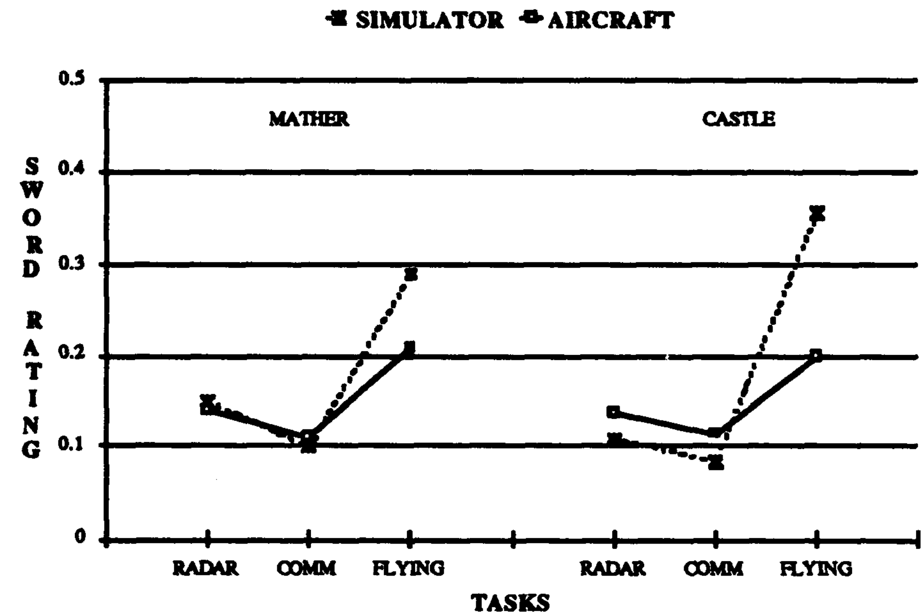

Figure 23. KC-135 SWORD ratings for the cell departure and join-up segment.

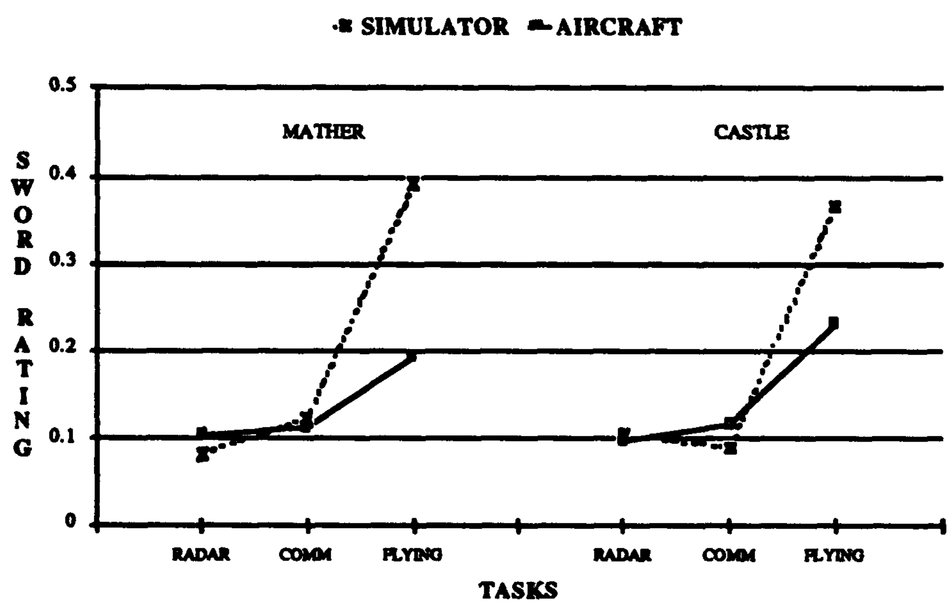

Figure 24. KC-10 SWORD ratings for the cell departure and join-up segment.

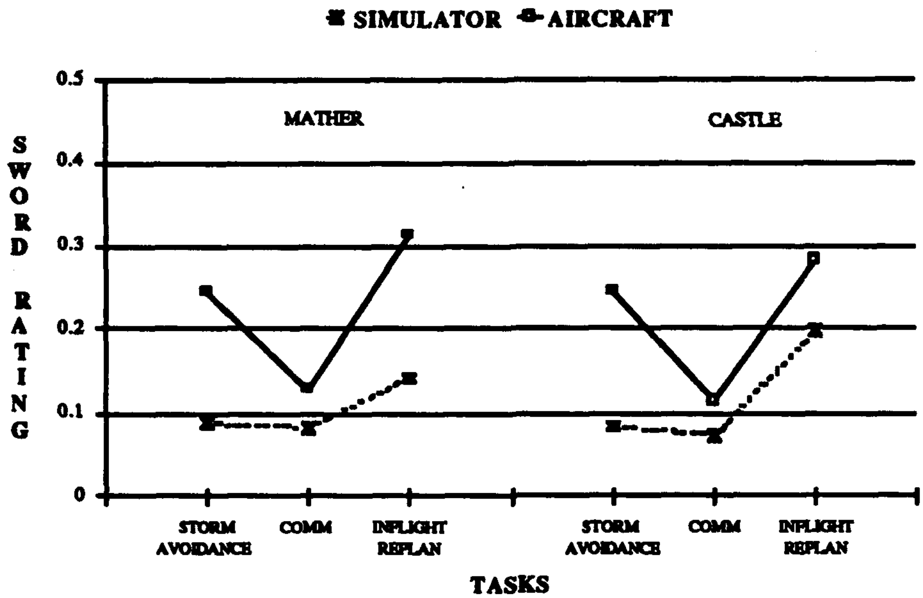

Figure 25. KC-135 SWORD ratings for the weather divert segment.

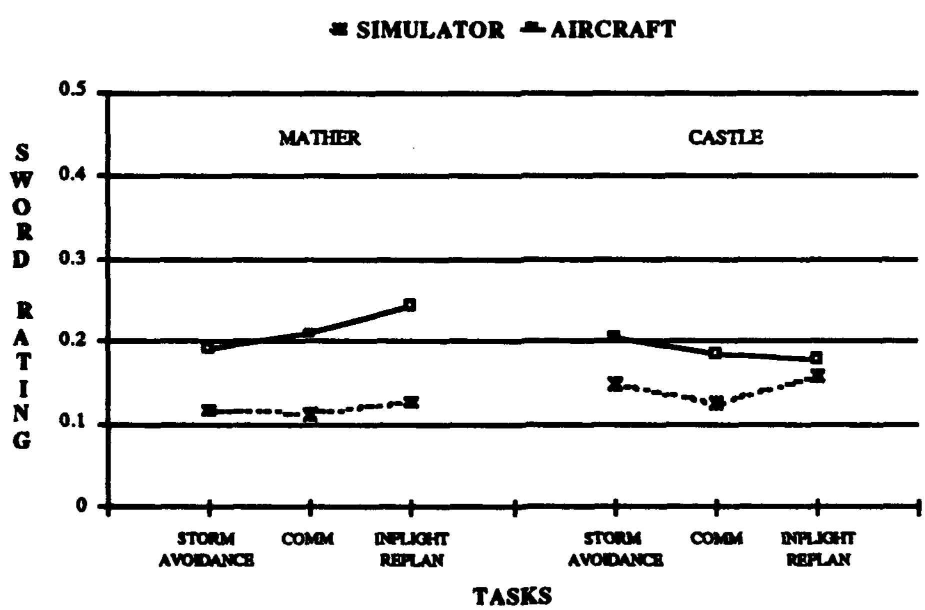

Figure 26. KC-10 SWORD ratings for the weather divert segment.

MCH

The Modified Cooper Harper scale (Figure 9) was used in conjunction with the mission specific questionnaires to evaluate specific workloads associated with five different tasks common to all missions: (1) Air refueling, (2) Communications, (3) Navigation, (4) Paperwork, and (5) Piloting. A review of figures 13 and 27 shows only the Castle mission as reaching or approaching a workload level of four, the level considered by CSEF personnel as the first level of concern. Below four, tasks were considered to be easily managed and of little concern.

Figures 28-30 represent the MCH results for the Minot, Mather, and Castle missions, respectively. The x-axis lists the particular task. The y-axis is the MCH numerical rating scale. The higher the numerical rating, the higher the perceived workload. The Minot mission provides the ratings for the KC-135 pilots, copilots, and navigators. The Mather and Castle Missions provide additional ratings for the KC-10 pilots. Figure 28, the Minot mission, indicates that no task was considered to be in a region of concern. The Mather mission (Figure 29) indicates that only the aerial refueling tasks were considered to be in an area of concern and then, only by the navigators. Castle mission results (Figure 30) were similarly expressed. The navigators identified aerial refueling, navigation, and piloting tasks as tasks with increased workload and, therefore, of concern. However, with the exception of the piloting task, no KC-135 pilot task rating was at or above four.

Several trends emerge from Figures 28-30. First, with one exception (Mather piloting task), navigators always rated the task workload in question highest among the crewmembers. Second, with the exception of the piloting task, the KC-10 pilots always rated the task in question as lowest. Third, generally speaking, the crews felt that all of the tasks were manageable. Each of these trends is explainable.

Since the navigators were only observers and cannot entirely tap into the internal stress levels that each of the pilots was experiencing, it is possible that their ratings may be biased. Additionally, the navigators had a vested interest in the project. Specifically, if the study demonstrated the feasibility of the design, the navigators might be out of a job. This concern was expressed to the experimenters several times. The KC-10 ratings reflect what might be considered training effects. Since the KC-10 crews fly a similar type of system, are trained in radar procedures and navigation techniques, and currently fly with no navigator, they were much more efficient in those procedures for which the KC-135 pilots were minimally qualified. The third trend exhibited in the piloting task was in large part attributed to the difficulty in flying a simulator instead of an actual aircraft, as explained earlier. Given the explanations above, the navigators' ratings were considered as the maximum workload that would probably occur in flight; whereas, the KC-10 workload ratings were identified as the minimal level of workload associated with each of the tasks.

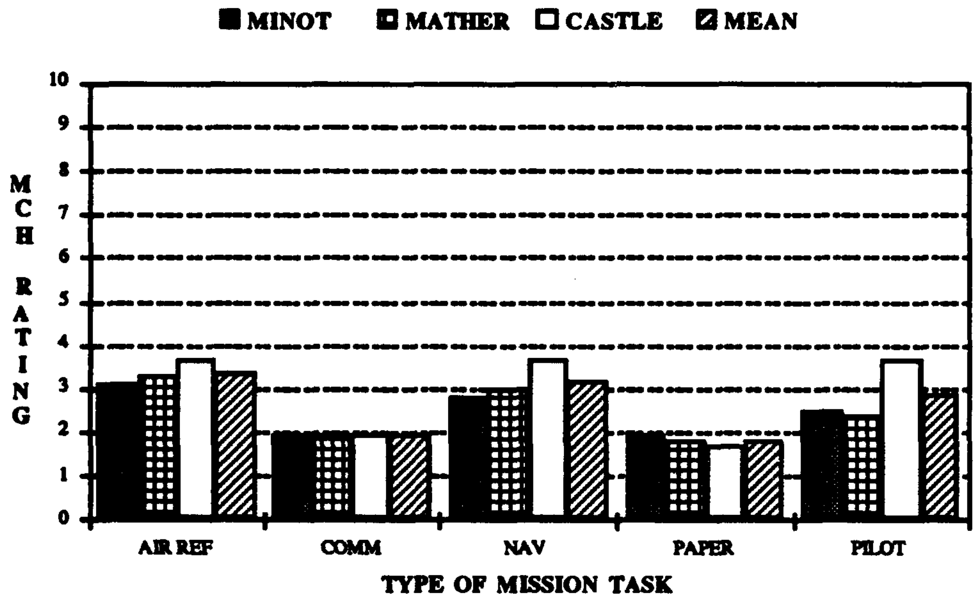

Figure 27. Overall task workload comparison for each mission.

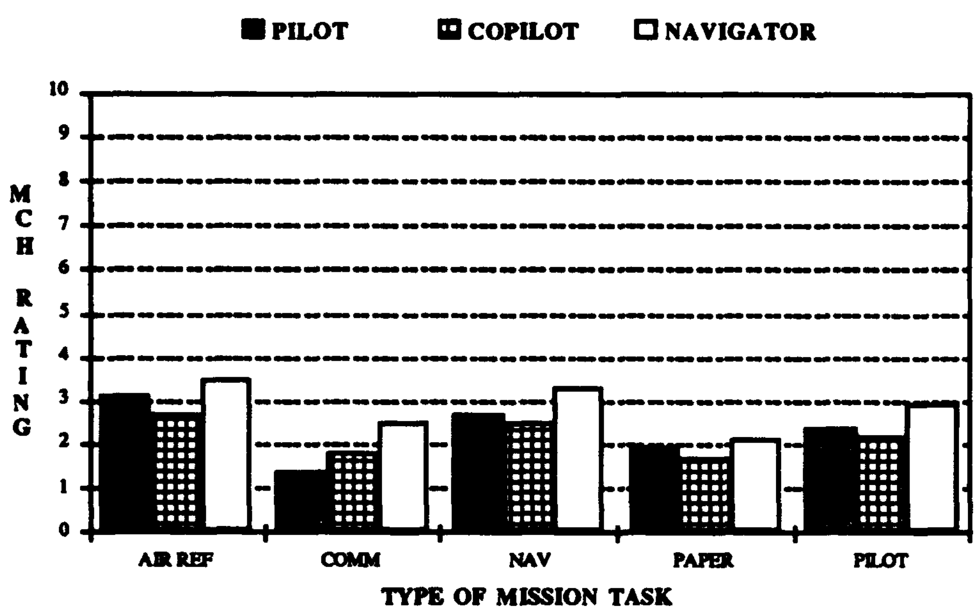

Figure 28. Minot task workload comparison by crew position.

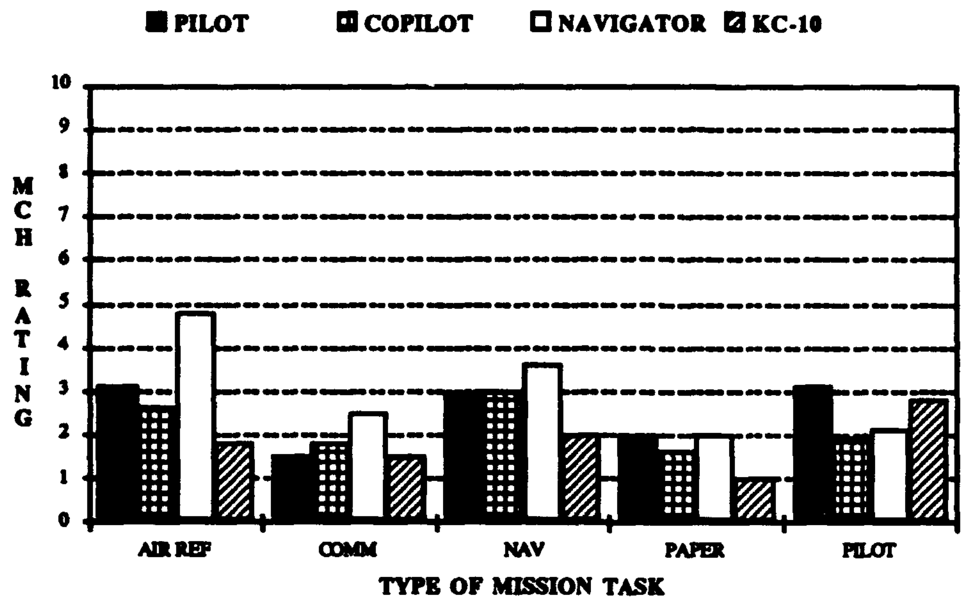

Figure 29. Mather task workload comparisons by crew position.

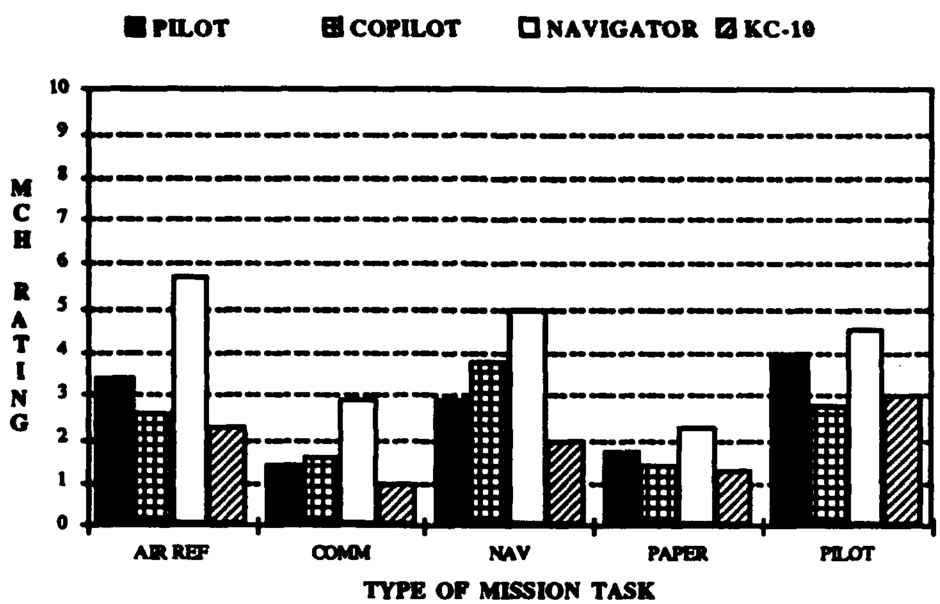

Figure 30. Castle task workload comparisons by crew position.

A final question identifying the percentage that each task was believed to be performed is presented in Figure 31. The x-axis again lists the same tasks as the MCH workload scale above. However, the y-axis is based on the relative percentage of time that each task was believed to be performed. Percentage of tasks across the missions remained relatively stable as shown in Figure 31. Only 4 percentage points separated percentage estimates in the worst case (AIR REF). However, as seen in Figure 32, task percentages varied dramatically between the crew positions (Minot and Mather mission resulted in similar results, but are not presented). Specifically, the pilots were involved much more with the piloting tasks; whereas, the copilots were much more involved with the navigation tasks. Since crews were not told who was to perform what tasks, this percentage breakdown provides information as to what function should be allocated to each of the crewmembers. The percentage breakdown directly supports the task workload allocation recommendations made earlier during the Function Analysis phase of this effort (Ward et al., 1991; Vol. I).

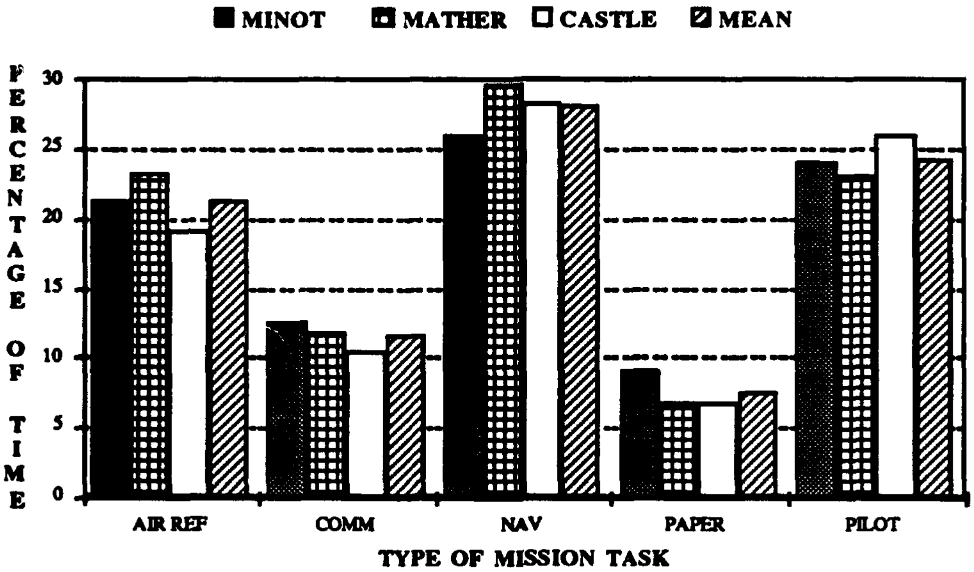

Figure 31. Task percentage comparisons across all three missions.

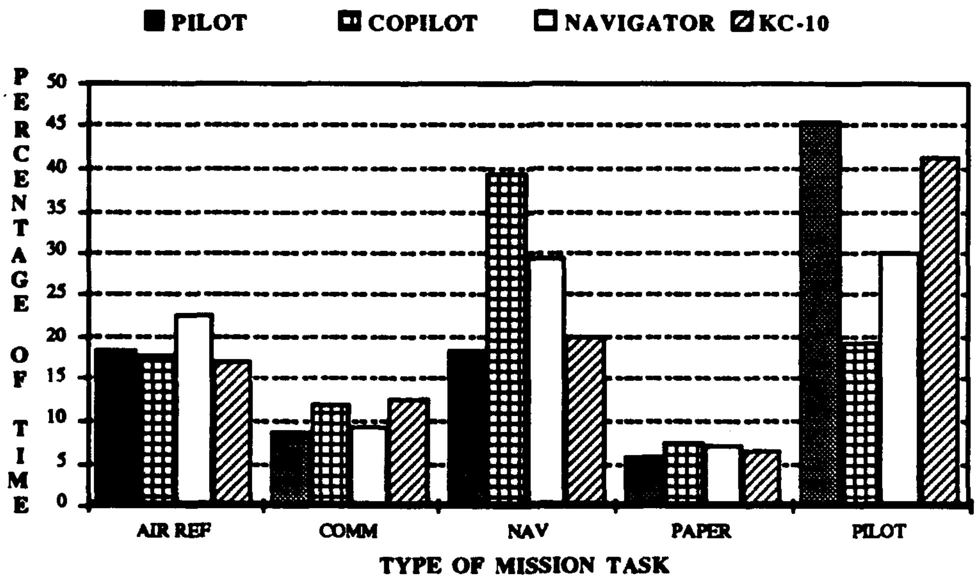

Figure 32. Castle task percentage comparisons by crew position.

Mission Questionnaires

Mission questionnaires (Appendices B-D) collected at the end of each mission were used to help determine critical areas involved with higher workloads as identified by the crewmembers. The questions were multiple choice with a section after each question for any explanations/comments an individual might deem necessary. The results of these questionnaires are summarized below.

Minot Mission

The total number of respondents answering the Minot mission questionnaire was 30 (10 pilots, 10 copilots, and 10 navigators). Over two-thirds of all respondents felt the various mission events (e.g., late takeoff, communications difficulties, early RZ time) resulted in only slight increases in workloads over a typical (average) flight mission. However, the hydraulic malfunction resulted in a moderate increase in workload. One pilot stated, "The simulator's navigation systems made the workload (associated with the malfunction) almost comparable to what it would be in the airplane with a 4 man crew." This indicates that the increase in workload resulting from the malfunction was not an artifact of the design but of the malfunction itself. Other comments suggested that such a mission would have been easily accomplished with a similarly designed cockpit. Figure 33 shows how each of the crew positions responded when asked if "a minimally experienced pilot with a minimally experienced copilot could have successfully flown this mission." The x-axis lists the crew position; the y-axis indicates the percentage of responses. The respondents (93%) felt confident that a minimally experienced crew could have flown this mission with this conceptual cockpit design. This further supports the feasibility of a two-person (No-Nav) conceptual cockpit design under lower workload conditions.

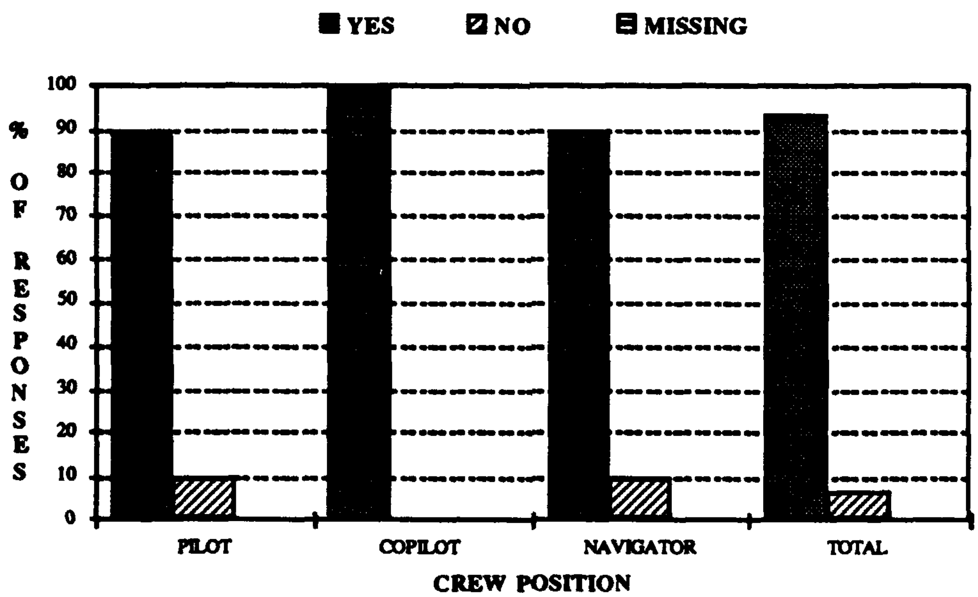

Figure 33. Minot mission minimally qualified crew response graph.

Mather Mission

The respondent pool included all of the subjects (KC-10 and KC-135 pilots, copilots, and navigators) for a total of 34 respondents. The subjects reported only slight increases in workload for each of the following flight events: (1) Late takeoff, (2) Cell departure and join-up, (3) Center-directed course change, (4) Thunderstorm avoidance, (5) GPS failure, and (6) Mission divert. None of the events questioned were rated as causing more than a slight increase in workload over that of a typical mission. Pilots indicated that a large percentage of the workload was a result of the unfamiliarity with the new equipment. All of the pilots felt that increased training would have resulted in lower stress and workload levels. Approximately 80% of the crewmembers (Figure 34) felt a "minimally qualified crew" could have successfully completed this mission. "Missing" refers to respondents who failed to answer the question. An interesting point is the fact that all of the KC-10 crewmembers felt confident that they could have flown this mission successfully. Keeping in mind the similarity of the training that KC-10 crew members undergo, these data suggest that increased training in equipment use and navigational techniques/procedures would prove very effective. These findings further suggest the conceptual design is keeping workload levels down to a manageable level.

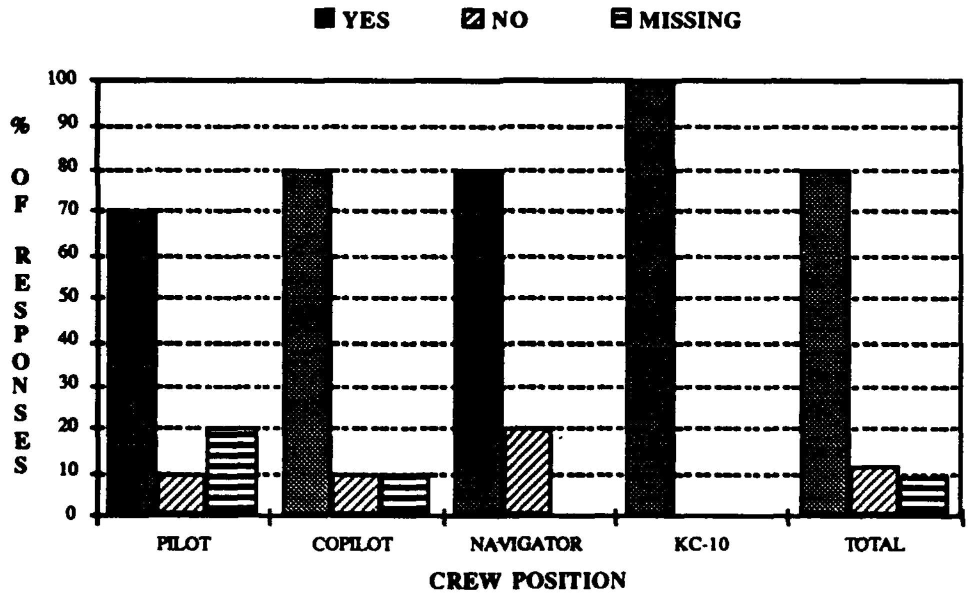

Figure 34. Mather mission minimally qualified crew response graph.

Castle Mission

The Castle subject pool was the same as for the Mather mission (n=34). Slight increases in workload over that of an average mission were reported for (1) Cell departure and join-up, (2) Thunderstorm avoidance, (3) GPS failure, and (4) Increased communications. Moderate increases were reported for (1) Air refueling track change, (2) Dual INS/GPS failure, and (3) the Missed approach/Weather divert to Beale AFB. A substantial increase in workload was identified for the autopilot failure. This was attributed to the fact that one pilot was then required to continually fly the aircraft manually. Several pilots felt that the workload associated with the autopilot failure was aggravated as a result of the simulator. Comments like "If the simulator would have trimmed up and remained trimmed like a real aircraft, it would have lessened a lot of the extra workload;" and workload increased "more so in the simulator than in real life due to the lack of flight sensation;" were common among the respondents. As stated earlier in the SWAT and SWORD results, workloads involved with flying the simulator as compared to that of the aircraft were always higher. Despite the increased workloads associated with this mission, 76% of all of the respondents (Figure 35) still felt, given this conceptual cockpit design, a "minimally qualified crew" could have successfully flown this mission.

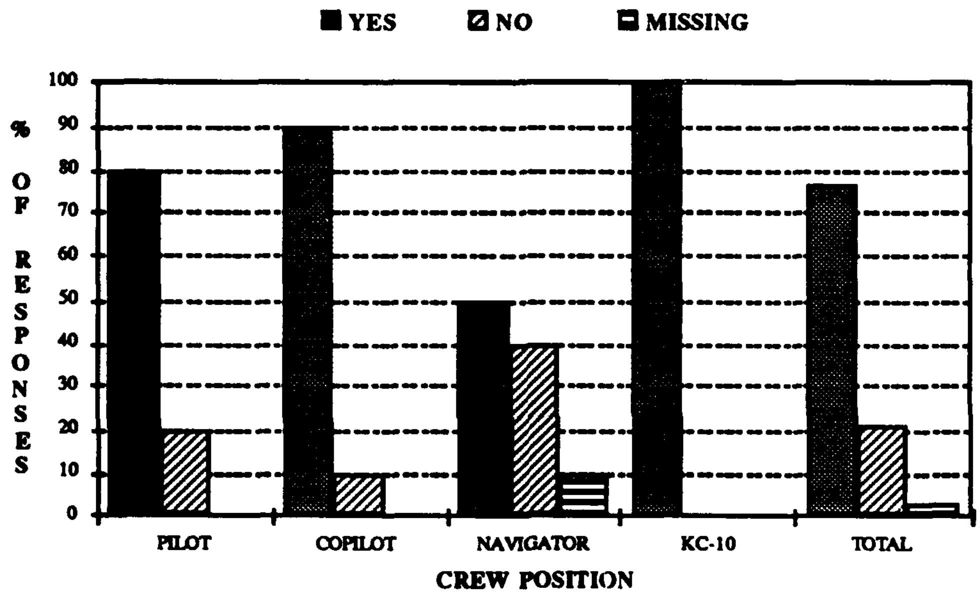

Figure 35. Castle mission minimally qualified crew response graph.

A review of Figure 36 presents the overall response percentages for all of the missions combined by crew position. In every instance, KC-10 crew members felt they could have successfully completed the mission; whereas, KC-135 crew members were more uncertain about such an endeavor. Eighty-five percent of the KC-135 pilots and copilots combined felt they could accomplish the various missions. KC-135 navigators were less optimistic. Only 73% of the navigators felt a minimally qualified crew could have completed the three missions. Crewmembers' comments explain much of the reservations as to why a mission with a minimally qualified crew might prove unsuccessful: "Extensive training would be required;" "Even with today's system it's still not a good idea;" and "Experience with the system, Center, timing, etc. is what counts;" These crewmembers' comments indicate their reservations are not a result of the system, but more a byproduct of the lack of experience. Several crewmembers who questioned the likelihood of successful mission completion also stated reservations as to whether a minimally qualified crew could have successfully flown the Castle mission, given the current aircraft configuration with a navigator. The overall conclusion based on the mission specific questionnaires and associated comments is that a two-man (No-Nav) conceptual cockpit is a viable approach for the KC-135.

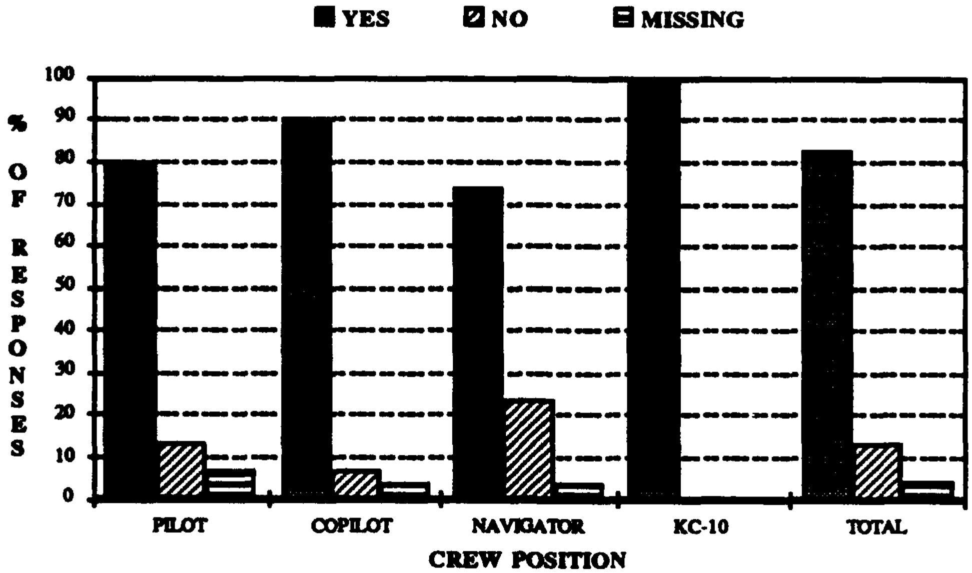

Figure 36. Overall responses for the minimally qualified aircrew question.

FEASIBILITY DEMONSTRATION FINDINGS

Results of the Subjective Workload Assessment Technique (SWAT), Subjective WORkload Dominance (SWORD) technique, the Modified Cooper-Harper (MCH) scale, the mission questionnaire, and the objective performance measures consistently support the following findings:

1. The manipulation of mission difficulty generally resulted in the expected pattern of results. The Minot mission was easiest, followed by the Mather mission, and the Castle mission was substantially more difficult.

2. The crewmembers' ratings of the percentage of time spent on the various tasks were relatively stable across missions. Additionally, the differences in percentage of time spent on each task varied by position as anticipated by the Ward et al. (1991) function analysis study.

3. The navigator consistently rated workloads higher than the pilots; whereas, the KC-10 pilots consistently rated workloads lower than their KC-135 counterparts.

4. The vast majority of crewmembers felt a minimally qualified pilot team could have successfully flown any of the three missions encountered, given the prototype design/system capabilities.

5. Increased workloads were encountered for the inflight emergency, random air refueling, and weather divert. However, none of these phases of flight resulted in workloads that were unmanageable.

CONCLUSION

THE FINDINGS OF THIS STUDY HAVE DEMONSTRATED THAT A TWO-PERSON (NO-NAV) COCKPIT IS FEASIBLE.

The above findings and conclusion are all based on the final design possessing similar system capabilities and functional requirements as those presented in the Crew Station Evaluation Facility's conceptual cockpit. The extent to which the two cockpits (the CSEF conceptual cockpit and the final KC-135 cockpit design) are similar in system capabilities/functional requirements represents the extent to which the findings are valid. If the final design is substantially different from that demonstrated in this study, the results of this study would be less generalizable. Based on this, recommendations for the functional requirements identified through this study to aid system program engineers in developing system specifications are discussed.

RECOMMENDATIONS

The following recommendations have been placed into three categories to support Directorate of Bombers and Tankers System Program Office requirements. They are:

(1) *Must haves* - equipment/capabilities that are substantial workload reducers and deemed absolutely essential for mission success. Failure to include these capabilities in the final cockpit design would result in workload levels that are unmanageable and mission success would be jeopardized.

(2) *Should haves* - equipment/capabilities that are moderate workload reducers deemed necessary for mission success. Failure to include these capabilities could result in higher workloads with the potential for increased mission failure.

(3) *Nice to Haves*- equipment/capabilities are workload reducers that would aid in mission success. Failure to include these capabilities would not necessarily jeopardize mission success, but could increase the workload levels of the crewmembers.

The categorization of the system capabilities were determined through the analyses of the data presented previously and from crewmember responses and comments to the system questionnaire (Appendix E). An explanation of each of the recommendations provides the rationale for its inclusion into the category. Additionally, several issues were raised through the course of the study that were not specifically addressed in the study. These issues are explained in detail in the Issues to Consider section.

Must Haves

1. *A navigational system that is highly accurate and reliable.* To eliminate the navigator, we assumed the system consisted of two INSs and a GPS. This system was very accurate, when fully operational. The loss of the GPS resulted in a slight workload increase for the Mather mission. However, the workload increased to a moderate workload level when the crew lost both of the INSs and the GPS together (Castle mission). This indicates the need for both an accurate and reliable navigation system. One crew stated the loss of both systems caused them to "consider navigating off TACANs and fly conventionally." This tacan capability would probably not exist in wartime or for overwater flight operations.

2. *Control Display Units (CDUs) with acceptable sized alphanumeric keys, function select keys, and line select keys to automate many of the navigation/control functions previously held by the navigator.* The CDUs provided a central place to control the various functions previously performed by the navigator. Crewmembers felt two CDUs were necessary to adequately perform the mission as this allowed "Each pilot to have his own display and make separate inputs." When queried as to the size of the keys, the pilots felt, "the oversized letters/numerals were a good size when compared to the FSAS and 757/767. The size in the simulator aids in seeing the pushbutton keys in dark conditions." Consequently, the size reduced the time needed in key recognition/key stroke. The other features of the CDU were all deemed as either moderately or completely acceptable indicating the CDUs were interfaced adequately.

3. *A ground Mission Planning System (MPS) with the capability to formulate the necessary database for a given mission during mission planning day and then be transferable into the aircraft via a floppy disk or similar type system.* An assumption made from the start of the study was that an MPS would be simulated that could load the entire database into the Mission Management System for each flight. If a crew was required to manually load the datapoints for each flight, an increase in time, workload, and human error would result. Additionally, should an inflight malfunction occur, the crew might be forced with manually reloading the entire database. An MPS with the above capability would greatly reduce this associated workload.

4. *An intercom system that allows the individual to tune the volume of each radio to the level desired, as radios will be controlled through the CDU/RRU (Remote Readout Unit).* Critical to the success of the communication system designed for the conceptual cockpit was the need to replace the older, less capable interphone system. Since the radio powerheads were removed from the overhead panel and all radio power was controlled through the CDU, radio volume control needed to be controlled. Previous flight crews had expressed several complaints about the inability to individually tune the UHF radios. Given a design change, and the availability of off-the-shelf intercom systems, the design incorporated an interphone system that allowed for each crewmember to individually tune their radios. The pilots found this type of interphone system to be essential to mission success.

5. *A Mission Management System with:*

a. *Easy to understand symbol conventions* .

b. *Left/Right scrolling between display pages and Up/Down scrolling between pages*. A pilot study performed prior to the actual study indicated the actual scrolling of display pages needed to be consistent within the MMS. The pilot study indicated that left/right scrolling was most suitable for scrolling between pages. Scrolling between pages refers to scrolling <u>between</u> pages that are functionally different (e.g., Power page to Start pages to Take off and Landing pages, etc.). Up/Down scrolling was assigned to scrolling <u>within</u> functional pages (e.g., Start 1 page to the Start 2 page, etc.).

c. *Waypoint database large enough to fly long combat type missions*. The database should be large enough to allow for the complete mission route of flight. Several comments identified the inadequacy of the current KC-135 inertial navigation system as being "too limiting" and "cumbersome." A larger database would allow for increased information to be inserted during mission planning day under low stress conditions resulting in lower inflight workloads.

d. *Mission database that includes 2-, 3-, 4-, and 5-letter ICAO identifiers, tacans, airfields, intersections; air refueling tracks; and Military Operating/Restricted areas for increased situation awareness, reduction in crew workload, and ease of inflight replanning*. The ability to address action points/geographical locations by their associated ICAO identifiers, MOA names, and AR track numbers, instead of strictly by latitude and longitude was identified by the crewmembers as a major workload saving capability used during inflight planning.

e. *Communication, Nav Aid, IFF Navigational Status, Direct To, Flightplan, Update Rendezvous/Orbit, Airborne Directed Approach, and Fuel Management capability pages, each tied to a dedicated function select key.* The results from both a previous pilot study and the present study indicated that head down time was related to which functions were assigned dedicated keys. Several off-the-shelf systems have the orbit function tied to a lower level menu and not directly to a function select key. Given the KC-135 mission, the conceptual cockpit design assigned the rendezvous/orbit function its own dedicated key. This resulted in decreased head down time and lower workload. Similar results were found for the other functions listed above.

f. *Rendezvous/Orbit capability providing the pilot with a pictorial view of his route of flight/orbit with associated turn range depicted, independent of the air-to-air tacan. Turn range and offset should be computer generated to further reduce crew workload during air refueling, a heavy workload time period.* Crewmembers found this capability as essential to keep workloads at a manageable level. One crew member stated, "This function was necessary without a navigator." Another pilot claimed it was, "A great idea to visually display the orbit area." The pilots identified the manual requirement to update the offset and turn range when it differed from what was originally set, as a limiting factor of this design. One pilot stated, "The system counts too much on pilot input" for the rendezvous/orbit function, while another pilot felt all data relevant to calculating turn range and offset should be automated, "No (unnecessary) thinking should be done by the pilots." A KC-10 pilot stated, "The KC-10 system figures out turn range and offset, all we have to tell it is receiver true airspeed" suggesting air refueling workload would be greatly decreased if turn range/offset were automated.

g. *A mode for receiver identification is required and should be controlled through the CDU.* When queried as to the need for the APN-69, approximately two-thirds of the respondents felt the need for the APN-69 beacon still existed. Several pilots stated the need for the APN-69 beacon was due to long range cell activity and for the air refueling rendezvous. In contrast, only four pilots felt they could successfully accomplish an air refueling rendezvous with the air-to-air tacan only. They generally felt the air-to-air tacan without an azimuth capability was limited in its functional value. Consequently, some additional means of receiver identification besides the air-to-air tacan would be beneficial. In summary, the need for a mode of receiver identification exists and should be controlled through the CDU, as all other air refueling functions are controlled through the CDU.

6. *A color weather radar display with:*

a. *Separate radar range controls for each of the pilots.* Eighty-seven percent of the pilots agreed separate controls for radar range should be incorporated. They cited the need to conduct cell and rendezvous operations close-in, while simultaneously scanning weather at a distance, as a major limitation of the CSEF conceptual cockpit design, which only had one set of radar controls. KC-10 pilots, who currently fly with two separate radar controls, stated emphatically that two separate control panels would be "most definitely" needed. Further clarification of the answers indicated that a single control panel often led to confusion and increased workload levels.

b. *A radar display on the Electronic Horizontal Situational Indicator.* Crewmembers did not believe the need for a dedicated radar was necessary. Again, 87% of the respondents preferred the radar display on the EHSI. One pilot summed up the lack of a need for a dedicated radar display, "It is good displaying it (radar presentation) on the EHSI since that's what the pilot looks at." However, in order to successfully perform radar operations at a reduced workload level, pilots strongly indicated that a color weather radar display would be essential. They did not believe radar operations would be manageable if a radar display similar to that in the KC-135 aircraft were used. Comments such as, "Color WX radar definitely decreases workload and mission difficulty," and "Absolutely necessary" were indicative of the majority of the responses regarding the need for a color radar. Additionally, the KC-10 pilots who all had previous experience with both a color and a monochrome radar display stated, "Color radar is definitely the best," further supporting the need for a color radar display on the EHSI.

c. *The receiver identification mode must be fully integrated via the CDU and the radar presentation on the EHSI.* The importance of receiver identification mode displayed on the EHSI was explained in 5g above.

7. *An EHSI with the following capabilities incorporated at both the pilot and copilot stations.*

a. *Full compass (360 degrees) and arc (approximately 90 degrees) map display capability.* The system was evaluated with both capabilities. Each capability was deemed essential for mission success. The study results indicated the pilot flying the aircraft generally had the full compass displayed, except for weather avoidance and cell departure and join-up. The pilot not flying the aircraft typically had an arc display presented to increase his navigational ability and situational awareness. The pilots stated this capability gave them increased situational awareness and reduced overall workload.

b. *Ability to overlay waypoints, navaids, and airports.* Pilots rated the ability to overlay waypoints, navaids, and airports directly onto the EHSI as a substantial overall workload reducer. When specifically asked which design functions were the most beneficial in accomplishing the mission, this capability was listed most often. The pilot stated it allowed them the opportunity to literally "see the big picture" resulting in increased situational awareness and decreased workload.

c. *Full-time course, distance, crosstrack, and time to go (TTG) readouts.* A full-time readout of the functions listed was deemed necessary to keep workloads down. The CSEF design provided the informatio; however, the information was not presented full-time. It was presented on a rotary switch with four other pieces of information or on different CDU display pages (e.g., INAV page). The pilots felt the constant switching to obtain this information was both time-consuming and detrimental to their situational awareness, since it required them to locate the rotary switch on the overhead panel. They felt a full-time presentation of the above information would provide them with the information most often provided to them by the navigator.

d. *Capability to display Groundspeed (GS), True Airspeed, Wind Direction and Velocity (W/V), and Drift Angle.* The need for the information listed above was identified for various phases of flight. The true airspeed enabled the pilots to better maintain airspeed at altitude. Groundspeed was effectively used during approach and landing and for estimated time of arrival calculations used to backup the navigation system. Wind information was important for alter heading calculations and pilot reports of the weather. Each piece of information was considered very valuable to the pilots and resulted in perceived lower workloads.

The importance of the EHSI capabilities and associated information is best summed up in the following statements by a KC-10 pilot. "The combination of all the information on the HSI is great! When does the KC-10 get this EHSI?"

Should Haves

1. *A Remote Readout Unit (RRU) with rapid radio and navigation aid frequency change capability. The unit should have its radio select buttons in an easily accessible location. Additionally, the pilots should be able to tune the navaids with either the frequency or the ICAO identifier. The unit should also have the capability to recall the last tuned frequency rapidly.* Pilots stated the RRU and its capabilities were "Very handy in the integration of pilot/copilot duties." They also claimed the RRU allowed for increased crew flexibility. The capability to recall the last tuned frequency at the press of the button was recognized as a real time-saver. They did, however, suggest the unit be reduced a little in size and concerns over whether the current color red would be suitable for all conditions of flight, specifically, bright sunlight were expressed (See Issues to Consider).

2. *An Electronic Attitude Director Indicator (EADI) that resembles pictorially the FD-109 system currently in the plane. It should also have a radar altitude and decision height readout capability.* The ability to display digitally the radar altitude and decision height was seen as very beneficial by the pilots. The pilots generally felt this helped their performance by reducing the need to check the analog radar altimeter. They also felt the presentation of the letters "DH" in the left center of the EADI provided them valuable information at a critical time in flight, although one pilot suggested a flashing "DH" of a different color might be more of an attention-getter. Another issue raised by one pilot, but beyond the scope of this study, was that of the increased reliability and maintainability of the EADI over the old analog ADI.

3. *A Fuel Savings Advisory/Caution Advisory System fully integrated through the CDU should be explored because such a system could greatly reduce their workload over the current system.* Due to the direction given the CSEF for the development of the conceptual design, the Fuel Savings Advisory System was not integrated through the CDU. This led to increased workload among the pilots because pilots were often forced to perform manual calculations due to the lack of system integration. Additionally, not integrating the system through the CDUs, would result in an additional CDU to operate the FSA/CAS, costing more money and taking up valuable cockpit space.

Nice to Haves

1. *A master caution light to enhance malfunction recognition in accordance with standard military practice. A warning/caution advisory panel although not a necessity, should be considered as the pilots would then have only one central place to look in case of a master caution light illuminating, decreasing recognition time.* Approximately 90% of the respondents considered the Master Caution light as very effective. The respondents also believed the analysis of the malfunction was sped up by immediate recognition of the problem via the warning/caution advisory panel. However, the pilots did feel the current system was adequate for most malfunctions and resulted in only slightly higher workloads.

2. *A digital countdown timer would aid the pilots during various phases of flight (i.e., non-precision approach).* This function was considered as nice to have because it enabled pilots to make accurate timings for missed approach procedures.

3. *Angle of Attack, Indicated Airspeed, Barometric Pressure, and Vertical Velocity displayed in the upper corners of the EADI would help reduce workload by lowering cross check scan range.* This information was liked by the pilots because it enabled them to focus more on the ADI, a primary flight reference. However, the majority of the pilots did

not feel it to be a necessity for mission success, since it was mainly redundant information that could be obtained from the analog instruments.

Issues to Consider

Throughout the study, several issues were raised that could not be resolved from the results of the study. These issues were either not addressed by the study or insufficient data were collected to draw substantive conclusions. The following is a list of those issues:

1. *Most suitable ranges and scales for the weather radar.* The particular ranges and scales for each range selection must be addressed. The baseline system provided various ranges with mid-range scales/markers (e.g., the 5-mile range had a mid-range scale/maker of 2.5). An earlier pilot study indicated that the 5- mile range should have 1-mile scale markers to assist in cell departure and join-up and rendezvous procedures. Similar determinations of the other ranges and scales are necessary to develop the best radar presentations.

2. *Ambient lighting considerations for the EADIs, EHSIs, CDUs, and RRUs.* The study was conducted under simulated nighttime environments. No evaluation was made concerning potential washout effects of sunlight or color degradation due to night goggles/helmet visors. Future studies should address these potential problems.

3. *Increased ground training requirements for each pilot in navigation, radar procedures, mission planning, and inflight replanning.* The most common comment by pilots throughout the course of the study concerned the limited amount of training. They felt a large percentage of the workload they experienced was the result of minimal training time. Additionally, given the navigator is trained for an extensive period of time (as much as 18 months in some aircraft) and the pilots will be required to perform what were previously navigator duties, it is reasonable to assume increased training will be required and should, therefore, be considered.

4. *A full radar presentation for the EHSI map display may increase situational awareness.* If both pilots are displaying a full compass rose, then the potential for inadvertent thunderstorm penetration exists because the conceptual design did not allow radar mapping to be displayed in full compass rose. This is a potential problem in the transition, approach and landing phases of flight when both pilots typically had the full compass rose displayed.

5. *An altitude warning signal.* Given the potential for altitude deviations and the removal of the additional set of eyes in the cockpit (i.e., navigator), consideration should be given for the possible inclusion of an altitude warning signal. Although this may be an artifact of inadequate training, an evaluation for the need of such a signal should be performed.

SUMMARY

This study was part three of a three-phase effort to demonstrate the feasibility of a two-person (No-nav) conceptual cockpit design. Ten KC-135 and 2 KC-10 crews flew several different missions over a 1-week period. Over the course of the week, various subjective (SWAT, SWORD, and MCH) and objective measures (e.g., airspeed, altitude) were used to demonstrate that such a design was feasible. Additionally, the subjective and objective measures were used in conjunction with questionnaire data to derive a set of functional requirements. These requirements were placed into one of three categories: Must haves, Should haves, and Nice to haves. A recap of each is shown in Table 6. From the study also sprung several issues of concern. These issues were not specifically addressed within the realm of the study, and should be considered in any future developmental efforts.

Table 6. Functional requirements and their categorical assignment.

MUST HAVE	SHOULD HAVE	NICE TO HAVE
MISSION MANAGEMENT SYSTEM	REMOTE READOUT UNIT	WARNING ADVISORY PANEL
CONTROL DISPLAY UNITS	EADI s	DIGITAL COUNTDOWN TIMER
MISSION PLANNING SYSTEM	INTEGRATED FSA/CAS	EADI DIGITAL READOUTS
NAVIGATION SYSTEM		
INTERPHONE SYSTEM		
COLOR WX RADAR		
EHSIs		

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APPENDIX A

SWORD RATING FORMS

Pilot(1) - CoPilot(2)

MINOT Mission (1) - Cruise Segment (1)

	Absolute		Very Strong		Strong		Weak		EQUAL		Weak		Strong		Very Strong		Absolute	
SIM-Haa																		SIM-Comm
SIM-Haa																		SIM-Nav
SIM-Haa																		REF-Haa
SIM-Haa																		REF-Comm
SIM-Haa																		REF-Nav
SIM-Comm																		SIM-Nav
SIM-Comm																		REF-Haa
SIM-Comm																		REF-Comm
SIM-Comm																		REF-Nav
SIM-Nav																		REF-Haa
SIM-Nav																		REF-Comm
SIM-Nav																		REF-Nav
REF-Haa																		REF-Comm
REF-Haa																		REF-Nav
REF-Comm																		REF-Nav

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

TASKS: Haa = Maintain Heading/Altitude/Airspeed
Comm = Communications
Nav = Navigation

Pilot(1) - CoPilot(2)

MINOT Mission (1) - Air Refueling (2)

	Absolute	Very Strong	Strong	Weak	EQUAL	Weak	Strong	Very Strong	Absolute	
SIM-Fuel										SIM-Comm
SIM-Fuel										SIM-Fly
SIM-Fuel										REF-Fuel
SIM-Fuel										REF-Comm
SIM-Fuel										REF-Fly
SIM-Comm										SIM-Fly
SIM-Comm										REF-Fuel
SIM-Comm										REF-Comm
SIM-Comm										REF-Fly
SIM-Fly										REF-Fuel
SIM-Fly										REF-Comm
SIM-Fly										REF-Fly
REF-Fuel										REF-Comm
REF-Fuel										REF-Fly
REF-Comm										REF-Fly

AIRCRAFT: SIM = Simulated KC-135

REF = Reference KC-135

(A, E, Q, R)

TASKS: Fuel = Manage fuel

Comm = Communications

Fly = Fly aircraft

Pilot(1) - CoPilot(2)

MINOT Mission (1) - Approach & Landing (3)

	Absolute	Very Strong	Strong	Weak	EQUAL	Weak	Strong	Very Strong	Absolute	
SIM-LOC										SIM-Comm
SIM-LOC										SIM-Nav
SIM-LOC										REF-LOC
SIM-LOC										REF-Comm
SIM-LOC										REF-Nav
SIM-Comm										SIM-Nav
SIM-Comm										REF-LOC
SIM-Comm										REF-Comm
SIM-Comm										REF-Nav
SIM-Nav										REF-LOC
SIM-Nav										REF-Comm
SIM-Nav										REF-Nav
REF-LOC										REF-Comm
REF-LOC										REF-Nav
REF-Comm										REF-Nav

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

TASKS: LOC = Maintain LOC/GS
Comm = Communications
Nav = Navigation Aid Set-up

Pilot(1) - CoPilot(2)

MATHER Mission (2) - Cell Departure & Join-up (4)

	Absolute	Very Strong	Strong	Weak	EQUAL	Weak	Strong	Very Strong	Absolute	
SIM-Radar										SIM-Comm
SIM-Radar										SIM-Fly
SIM-Radar										REF-Radar
SIM-Radar										REF-Comm
SIM-Radar										REF-Fly
SIM-Comm										SIM-Fly
SIM-Comm										REF-Radar
SIM-Comm										REF-Comm
SIM-Comm										REF-Fly
SIM-Fly										REF-Radar
SIM-Fly										REF-Comm
SIM-Fly										REF-Fly
REF-Radar										REF-Comm
REF-Radar										REF-Fly
REF-Comm										REF-Fly

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

TASKS: Radar = Radar Operations
Comm = Communications
Fly = Fly Aircraft

Pilot(1) - CoPilot(2)

MATHER Mission (2) - Air Refueling (5)

	Absolute		Very Strong		Strong		Weak		EQUAL		Weak		Strong		Very Strong		Absolute	
SIM-Fuel																		SIM-Comm
SIM-Fuel																		SIM-Fly
SIM-Fuel																		REF-Fuel
SIM-Fuel																		REF-Comm
SIM-Fuel																		REF-Fly
SIM-Comm																		SIM-Fly
SIM-Comm																		REF-Fuel
SIM-Comm																		REF-Comm
SIM-Comm																		REF-Fly
SIM-Fly																		REF-Fuel
SIM-Fly																		REF-Comm
SIM-Fly																		REF-Fly
REF-Fuel																		REF-Comm
REF-Fuel																		REF-Fly
REF-Comm																		REF-Fly

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

TASKS: Fuel = Manage fuel
Comm = Communications
Fly = Fly aircraft

Pilot(1) - CoPilot(2)

MATHER Mission (2) - Weather/Divert (6)

	Absolute		Very Strong		Strong		Weak		EQUAL		Weak		Strong		Very Strong		Absolute	
SIM-Storm																		SIM-Comm
SIM-Storm																		SIM-Plan
SIM-Storm																		REF-Storm
SIM-Storm																		REF-Comm
SIM-Storm																		REF-Plan
SIM-Comm																		SIM-Plan
SIM-Comm																		REF-Storm
SIM-Comm																		REF-Comm
SIM-Comm																		REF-Plan
SIM-Plan																		REF-Storm
SIM-Plan																		REF-Comm
SIM-Plan																		REF-Plan
REF-Storm																		REF-Comm
REF-Storm																		REF-Plan
REF-Comm																		REF-Plan

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

TASKS: Storm = ID Thunderstorm/Tune Radar
Comm = Center communication/coordination
Plan = Adjust flight plan

Pilot(1) - CoPilot(2)

CASTLE Mission (3) - Cell Departure & Join-up (7)

	Absolute	Very Strong	Strong	Weak	EQUAL	Weak	Strong	Very Strong	Absolute	
SIM-Radar										SIM-Comm
SIM-Radar										SIM-Fly
SIM-Radar										REF-Radar
SIM-Radar										REF-Comm
SIM-Radar										REF-Fly
SIM-Comm										SIM-Fly
SIM-Comm										REF-Radar
SIM-Comm										REF-Comm
SIM-Comm										REF-Fly
SIM-Fly										REF-Radar
SIM-Fly										REF-Comm
SIM-Fly										REF-Fly
REF-Radar										REF-Comm
REF-Radar										REF-Fly
REF-Comm										REF-Fly

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

TASKS: Radar = Radar Operations
Comm = Communications
Fly = Fly Aircraft

Pilot(1) - CoPilot(2)

CASTLE Mission (3) - Air Refueling (8)

	Absolute	Very Strong	Strong	Weak	EQUAL	Weak	Strong	Very Strong	Absolute	
SIM-Fuel										SIM-Comm
SIM-Fuel										SIM-Fly
SIM-Fuel										REF-Fuel
SIM-Fuel										REF-Comm
SIM-Fuel										REF-Fly
SIM-Comm										SIM-Fly
SIM-Comm										REF-Fuel
SIM-Comm										REF-Comm
SIM-Comm										REF-Fly
SIM-Fly										REF-Fuel
SIM-Fly										REF-Comm
SIM-Fly										REF-Fly
REF-Fuel										REF-Comm
REF-Fuel										REF-Fly
REF-Comm										REF-Fly

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

TASKS: Fuel = Manage fuel
Comm = Communications
Fly = Fly aircraft

Pilot(1) - CoPilot(2)

CASTLE Mission (3) - Weather/Divert (9)

	Absolute	Very Strong	Strong	Weak	EQUAL	Weak	Strong	Very Strong	Absolute	
SIM-Storm										SIM-Comm
SIM-Storm										SIM-Plan
SIM-Storm										REF-Storm
SIM-Storm										REF-Comm
SIM-Storm										REF-Plan
SIM-Comm										SIM-Plan
SIM-Comm										REF-Storm
SIM-Comm										REF-Comm
SIM-Comm										REF-Plan
SIM-Plan										REF-Storm
SIM-Plan										REF-Comm
SIM-Plan										REF-Plan
REF-Storm										REF-Comm
REF-Storm										REF-Plan
REF-Comm										REF-Plan

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

TASKS: Storm = ID Thunderstorm/Tune Radar
Comm = Center communication/coordination
Plan = Adjust flight plan

Pilot(1) - CoPilot(2)

ALL Missions (4) - Overall Workload (10)

	Absolute	Very Strong	Strong	Weak	EQUAL	Weak	Strong	Very Strong	Absolute	
SIM-Minot										SIM-Mather
SIM-Minot										SIM-Castle
SIM-Minot										REF-Minot
SIM-Minot										REF-Mather
SIM-Minot										REF-Castle
SIM-Mather										SIM-Castle
SIM-Mather										REF-Minot
SIM-Mather										REF-Mather
SIM-Mather										REF-Castle
SIM-Castle										REF-Minot
SIM-Castle										REF-Mather
SIM-Castle										REF-Castle
REF-Minot										REF-Mather
REF-Minot										REF-Castle
REF-Mather										REF-Castle

AIRCRAFT: SIM = Simulated KC-135
REF = Reference KC-135
(A, E, Q, R)

MISSIONS: Minot
Mather
Castle

APPENDIX B

MINOT MISSION QUESTIONNAIRE

Minot Mission

Questionnaire

This questionnaire is a mission specific questionnaire concerning the various events and actions undergone during the last mission. You should answer the questionnaire from your own individual perspective by circling the appropriate answer. If you feel that any question needs further explanation, please feel free to ask one of the experimenters for clarification. If you feel no one answer is adequate, please use the comments section after each question to elaborate on it. A comments section has been provided after each question to allow you to actively express all concerns you might have about a given question, mission, or instrument. You are encouraged to use the comments section whenever possible. However, do not feel you must comment on every question. For those questions requiring more space than that provided, simply turn the page over and write on the back. Additional comment space is also provided on the last page of the questionnaire.

PERSONAL DATA

Name (Optional):____

Grade: O-1 O-2 O-3 O-4 O-5 0-6

Age:______________________ Sex:__________________________

Aeronautical Rating: Pilot / Nav — Senior Pilot / Senior Nav — Master Pilot / Master Nav

Crew Position: Nav IN CP P/AC IP

Organization:____

Duty Station:____

Total Flying Hours:____

Total KC-135 Flying Hours:____________________________________

Total Hours Current Crew Position:______________________________

Time Since Last Flight:________ Months ________Days

KC-135 Aircraft Model Currently Flying:_________

Minot Mission

1. **The late takeoff caused (a) _______ increase in mission difficulty/aircrew workload.**

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

2. **Were you able to identify your receiver on radar prior to your turn inbound to the ARIP?**

a. Yes b. No

Comments: ____

____

____

____

3. **The receiver's early arrival at the ARIP caused (a) _______ increase in mission difficulty/aircrew workload.**

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

4. **The communication difficulties encountered at EAR caused (a) _______ increase in mission difficulty/aircrew workload.**

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

5. The hydraulic failure caused (a) _______ increase in mission difficulty/aircrew workload.

a. No   b. Slight   c. Moderate   d. Substantial

Comments: ____

____

____

____

6. What type of work-around procedures were used to overcome the difficulties encountered during this mission?

Comments: ____

____

____

____

7. Did you encounter any other problem areas during this mission? (Please explain in comments section)

a. Yes   b. No

Comments: ____

____

____

____

8. Which pieces of equipment and/or design functions were particularly helpful in accomplishing this mission? (Please explain in comment sections)

Comments: ____

____

____

____

9. Which pieces of equipment and/or design functions were extremely hard to use and, consequently, caused high workload? (Please explain in comments section)

Comments:____

____

____

____

10. Please recommend any improvements to the current equipment design/interface that you feel would improve aircrew efficiency and reduce aircrew workload?

Comments: ____

____

____

____

11. What adjective best describes the overall difficulty of this mission?

a. Easy b. Medium c. Hard

12. Using the modified Cooper-Harper (C-H) scale provided, how would you rate the mission just flown?

1 2 3 4 5 6 7 8 9 10

13. What percentage of your total workload came from each of the following tasks? Using the modified C-H scale, rate your workload for each task.

	%	Rating
Aerial Refueling Tasks	_____	_____
Communication Tasks	_____	_____
Navigation Tasks	_____	_____
Paperwork Tasks	_____	_____
Piloting Tasks	_____	_____
Other	_____	_____

14. For the previous mission, rate your workload as compared to what you think it would have been with the present KC-135 system and a navigator. With the system that I just flew my workload was _______.

a. Substantially decreased
b. Moderately decreased
c. Slightly decreased
d. Not changed
e. Slightly increased
f. Moderately increased
g. Substantially increased

Comments: ____

____

____

____

15. Provided adequate training, could a minimally experienced pilot with a minimally experienced copilot successfully fly this mission?

a. Yes b. No

Comments: ____

____

____

____

16. Given the mission just flown, could a single pilot (i.e., one pilot is incapacitated) have performed this mission?

a. Yes b. No

Comments: ____

____

____

____

17. The following space is provided for you to elaborate on questions 1-16 or for you to identify any other concerns that you might have.

APPENDIX C

MATHER MISSION QUESTIONNAIRE

Mather Mission

Questionnaire

This questionnaire is a mission specific questionnaire concerning the various events and actions undergone during the last mission. You should answer the questionnaire from your own individual perspective by circling the appropriate answer. If you feel that any question needs further explanation, please feel free to ask one of the experimenters for clarification. If you feel no one answer is adequate, please use the comments section after each question to elaborate on it. A comments section has been provided after each question to allow you to actively express all concerns you might have about a given question, mission, or instrument. You are encouraged to use the comments section whenever possible. However, do not feel you must comment on every question. For those questions requiring more space than that provided, simply turn the page over and write on the back. Additional comment space is also provided on the last page of the questionnaire.

PERSONAL DATA

Name (Optional):____

Grade: O-1 O-2 O-3 O-4 O-5 0-6

Age:____________________ Sex:________________________

Aeronautical Rating:	Pilot	Senior Pilot	Master Pilot
	Nav	Senior Nav	Master Nav

Crew Position: Nav IN CP P/AC IP

Organization:____

Duty Station:____

Total Flying Hours:______________________________________

Total KC-135 Flying Hours:_________________________________

Total Hours Current Crew Position:____________________________

Time Since Last Flight:________ Months ________Days

KC-135 Aircraft Model Currently Flying:________

Mather Mission

1. The late takeoff caused (a) _______ increase in mission difficulty/crew workload.

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

2. The cell departure/join-up requirement caused (a) ______ increase in mission difficulty/aircrew workload.

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

3. The implementation of the center directed course change caused (a) _______ increase in mission difficulty/crew workload.

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

4. Thunderstorm avoidance caused (a) _______ increase in mission difficulty/crew workload.

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

5. **Prior to GPS failure, did you detect your INSs were drifting?** (Please explain when and how you detected your INSs were drifting in the Comments section).

a. Yes b. No

Comments: ____

____

____

____

6. **The failure of the GPS system caused (a) ________ increase in aircrew workload?**

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

7. **The Command Post imposed divert to Castle AFB caused (a) ________ increase in mission difficulty/aircrew workload?**

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

8. **Which pieces of equipment and/or design functions were particularly helpful in accomplishing this mission?** (Please explain in comment sections)

Comments: ____

____

____

____

9. **Which pieces of equipment and/or design functions were extremely hard to use and, consequently, caused a high workload?** (Please explain in comments section)

Comments:____

____

____

____

10. **Please recommend any improvements to the current equipment design/interface that you feel would improve aircrew efficiency and reduce aircrew workload?**

Comments: ____

____

____

____

11. **What adjective best describes the overall difficulty of this mission?**

a. Easy   b. Medium   c. Hard

12. **Using the modified Cooper-Harper scale provided, how would you rate the mission just flown?**

1   2   3   4   5   6   7   8   9   10

13. **What percentage of your total workload came from each of the following tasks. Using the modified C-H scale, rate your workload for each task?**

	%	**Rating**
Aerial Refueling Tasks	____	____
Communication Tasks	____	____
Navigation Tasks	____	____
Paperwork Tasks	____	____
Piloting Tasks	____	____
Other	____	____

14. For the previous mission, rate your workload as compared to what you think it would have been with the present KC-135 system and a navigator. With the system that I just flew my workload was ________.

a. Substantially decreased
b. Moderately decreased
c. Slightly decreased
d. Not changed
e. Slightly increased
f. Moderately increased
g. Substantially increased

Comments: ____

____

____

____

15. Provided adequate training, could a minimally experienced pilot with a minimally experienced copilot successfully fly this mission?

a. Yes b. No

Comments: ____

____

____

16. Given the mission just flown, could a single pilot (i.e., one pilot is incapacitated) have performed this mission?

a. Yes b. No

Comments: ____

____

____

____

17. **The following space is provided for you to elaborate on questions 1-16 or for you to identify any other concerns that you might have.**

APPENDIX D

CASTLE MISSION QUESTIONNAIRE

Castle Mission

Questionnaire

This questionnaire is a mission specific questionnaire concerning the various events and actions undergone during the last mission. You should answer the questionnaire from your own individual perspective by circling the appropriate answer. If you feel that any question needs further explanation, please feel free to ask one of the experimenters for clarification. If you feel no one answer is adequate, please use the comments section after each question to elaborate on it. A comments section has been provided after each question to allow you to actively express all concerns you might have about a given question, mission, or instrument. You are encouraged to use the comments section whenever possible. However, do not feel you must comment on every question. For those questions requiring more space than that provided, simply turn the page over and write on the back. Additional comment space is also provided on the last page of the questionnaire.

PERSONAL DATA

Name (Optional):____

Grade: O-1 O-2 O-3 O-4 O-5 0-6

Age:____________________ **Sex:**________________________

Aeronautical Rating:	Pilot	Senior Pilot	Master Pilot
	Nav	Senior Nav	Master Nav

Crew Position: Nav IN CP P/AC IP

Organization:____

Duty Station:____

Total Flying Hours:____________________________________

Total KC-135 Flying Hours:________________________________

Total Hours Current Crew Position:____________________________

Time Since Last Flight:________ **Months** ________**Days**

KC-135 Aircraft Model Currently Flying:________

Castle Mission

1. **The autopilot failure caused (a) ____ increase in mission difficulty/aircrew workload.**

   a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

2. **The cell departure/join-up requirement caused (a) ______ increase in mission difficulty/aircrew workload.**

   a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

3. **The air refueling area change caused (a) _____ increase in mission difficulty/aircrew workload.**

   a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

4. **Thunderstorm avoidance caused (a) _______ increase in mission difficulty/crew workload.**

   a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

5. Prior to GPS failure, did you detect your INSs were drifting? (Please explain when and how you detected your INSs were drifting in the Comments section).

a. Yes b. No

Comments: ____

____

____

____

6. The failure of the GPS system caused (a) _______ increase in mission difficulty/aircrew workload.

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

7. The failure of both INS systems caused (a) _______ increase in mission difficulty/aircrew workload.

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

8. The weather divert to Beale AFB caused (a) _______ increase in mission difficulty/aircrew workload.

a. No b. Slight c. Moderate d. Substantial

Comments: ____

____

____

____

9. The ability to call up individual air refueling tracks/military operating areas caused (a) ________ decrease in aircrew workload.

a. No   b. Slight   c. Moderate   d. Substantial

Comments: ____

____

____

____

10. The ability to fly to an airport/IAF by the insertion of the airport/IAF identifier during a weather divert caused (a) _____ decrease in aircrew workload.

a. No   b. Slight   c. Moderate   d. Substantial

Comments: ____

____

____

____

11. The increased volume of radio traffic and radio frequency changes caused (a) _______ increase in mission difficulty/aircrew workload.

a. No   b. Slight   c. Moderate   d. Substantial

Comments: ____

____

____

____

12. Which pieces of equipment and/or design functions were particularly helpful in accomplishing this mission? (Please explain in comment sections)

Comments: ____

____

____

____

13. Which pieces of equipment and/or design functions were extremely hard to use and, consequently, caused a high workload? (Please explain in comments section)

Comments:____

____

____

____

14. Please recommend any improvements to the current equipment design/interface that you feel would improve aircrew efficiency and reduce aircrew workload?

Comments: ____

____

____

____

15. What adjective best describes the overall difficulty of this mission?

a. Easy b. Medium c. Hard

16. Using the modified Cooper-Harper (C-H) scale provided, how would you rate the mission just flown?

1 2 3 4 5 6 7 8 9 10

17. What percentage of your total workload came from each of the following tasks. Using the modified C-H scale, rate your workload for each task?

	%	**Rating**
Aerial Refueling Tasks	____	____
Communication Tasks	____	____
Navigation Tasks	____	____
Paperwork Tasks	____	____
Piloting Tasks	____	____
Other	____	____

18. For the previous mission, rate your workload as compared to what you think it would have been with the present KC-135 system and a navigator. With the system that I just flew my workload was _______.

a. Substantially decreased
b. Moderately decreased
c. Slightly decreased
d. Not changed
e. Slightly increased
f. Moderately increased
g. Substantially increased

Comments: ____

____

____

____

19. Provided adequate training, could a minimally experienced pilot with a minimally experienced copilot successfully fly this mission?

a. Yes   b. No

Comments: ____

____

____

20. Given the mission just flown, could a single pilot (i.e., one pilot is incapacitated) have performed this mission?

a. Yes   b. No

Comments: ____

____

____

21. The following space is provided for you to elaborate on questions 1-20 or for you to identify any other concerns that you might have.

APPENDIX E

SYSTEMS QUESTIONNAIRE

Systems Questionnaire

The following questions will address issues concerning the physical characteristics and operation of the various systems used during this study. Your answers to these questions should be made from the standpoint of the operational utility in the KC-135 air refueling mission. Space has been provided for comments after each question. If further space is needed, please continue on the backside of the page. Do not feel you have to comment on every question. When asked about the location of the various pieces of equipment, please consider the location of the equipment in relationship to how you answered previous questions. For example, it would be impossible to put the CDU and a warning caution advisory system in the exact same location. All comments and ideas you may have to improve the operational utility of the equipment and reduce crew workload will be greatly appreciated.

Analog Flight Instruments

1. **Please answer Yes (Y) or No (N) to the following questions for each of the analog flight instruments listed below. Please comment on all "No" answers.**

Size: Is the size of the instrument adequate for the application?
Number: Are there enough of the instruments (as backups) in the cockpit?
Location: Is the location of the instrument adequate?
Necessity: Is the the instrument necessary or critical?

Instrument	Size	Number	Location	Necessity
Attitude Director Indicator (ADI)	____	____	____	____.
Altimeter	____	____	____	____.
Angle of Attack (AOA) Indicator	____	____	____	____.
Clock	____	____	____	____.
Indicated Airspeed (IAS)	____	____	____	____.
Mach Indicator	____	____	____	____.
Radio Altimeter	____	____	____	____.
Radio Magnetic Indicator (RMI)	____	____	____	____.
Vertical Velocity Indicator (VVI)	____	____	____	____.

Comments:____

____

____

____

____

____

2. **Should the backup ADI have flight direction capability?** Yes No

Comments:____

3. **Would a digital clock adequately replace the analog clock?** Yes No

4. **Is a chronograph (count up) function needed?** Yes No

5. **Is a timer (count down) function needed?** Yes No

Comments (3-5):____

6. **Should the Mach and Indicated Airspeed instruments be combined?**
   Yes No

Comments:____

7. **Based on your experience, the reliability of the current radio altimeter is** __________.

   a. Completely unacceptable
   b. Moderately unacceptable
   c. Borderline
   d. Moderately acceptable
   e. Completely acceptable

Comments:____

Digital Warning Caution Advisory (WCA) Display

1. **The size of the WCA display was ________, considering its possible application.**

   Too small   About right   Too large

Comments:____

____

____

____

2. **The size of the characters was ________, considering viewing distance.**

   Too small   About right   Too large

Comments:____

____

____

____

3. **The dimming (brightness) capability of the display was ________.**

   a. Completely unacceptable
   b. Moderately unacceptable
   c. Borderline
   d. Moderately acceptable
   e. Completely acceptable

Comments:____

____

____

____

4. The location of the display was ____________. (Please explain below.)

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

5. What specific warnings, cautions, and/or advisories would you like to see on this display?

Comments:____

6. What warnings, cautions, and/or advisories would you prefer not be displayed?

Comments:____

7. Was the Master Caution light effective? Yes No

Comments:____

8. Would you prefer a multiple-sensory WCA message system?

a. No, light only.
b. Yes, light and tone.
c. Yes, light and voice.
d. Yes, light , tone, and voice.

Comments:____

____

____

____

9. Have you previously been exposed to digitally displayed engine instruments? Yes No

Comments:____

____

____

____

10. Do you feel digitally displayed engine instruments are necessary for the KC-135? Yes No

Comments:____

____

____

____

11. Digital Engine Displays have the capability to change color, alerting the pilot of an out-of-tolerance condition. This capability ____________ my answer to question 9?

a. Changes
b. Supports
c. Does not affect.

Comments:____

____

____

____

12. Digital Engine Displays have the capability to integrate WCA information with engine instruments. This capability ____________ my answer to question 9?

a. Changes
b. Supports
c. Does not affect.

Comments:____

____

____

____

Control Display Unit (CDU)

This section asks several question concerning the physical characteristics of the CDU.

1. The location of the CDU for optimal use of the Mission Management System (MMS) was _________?

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

2. The dimming (brightness) capability of the CDU was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

3. The size of the alphanumeric push button keys is ___________.

Too small About right Too large

Comments:____

4. The size of the function select keys (FSK) is __________.

Too small About right Too large

Comments:____

____

____

____

5. The size of the line select keys (LSK) is __________.

Too small About right Too large

Comments:____

____

____

____

6. The tactile feedback for switch activation without gloves was ______.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

____

____

____

7. The tactile feedback for switch activation with gloves on was ______.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

____

____

____

8. The readability of the alphanumeric key legend/lettering was _________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

____

____

____

9. The readability of the function select key legend/lettering was _________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

____

____

____

10. The readability of the CDU lettering/symbols was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

____

____

____

11. Were any of the pages cluttered? Yes No (If yes, please list below.)

Comments:____

____

____

____

12. Did you experience any parallax/distortion problems with any of the CDU displays? Yes No (If yes, please explain below.)

Comments:____

____

____

____

Mission Management System Operation

This section will address the operating procedures associated with the functions of the Mission Management System (MMS).

1. **Were the symbol conventions (e.g., colons, arrows, etc.) easy to use and understand?** Yes No (If no, please explain below.)

Comments:____

____

____

____

2. **The ________ should be used when slewing between display pages.**

   a. Up/Down arrow keys b. Right/Left arrow keys

Comments:____

____

____

____

3. **The flight plan loading options were ____________.** (Please explain below.)

   a. Completely unacceptable
   b. Moderately unacceptable
   c. Borderline
   d. Moderately acceptable
   e. Completely acceptable

Comments:____

____

____

____

4. Flight plan modifications/correction implementation was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments:____

____

____

____

5. Which Direct-To function capability did you prefer?

a. The DIR key capability.
b. The Waypoint Summary Page capability.
c. Both capabilities were equally good.
d. Neither capability was adequate.
e. I did not use either capability.

(Please explain your answer in further detail below.)

Comments:____

____

____

____

6. The overfly update capability of this system was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

(Please explain what you liked or disliked about this capability below.)

Comments:____

____

____

____

7. Was the Tacan update capability of this system easy to use? Yes No

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

(Please explain what you liked or disliked about this capability below.)

Comments:____

8. Was the holding pattern set-up capability beneficial? Yes No

9. The ease of use of the holding pattern capability was ____________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments (8-9):____

10. Was the Rendezvous (Point Parallel) set-up capability beneficial?
Yes No

11. The ease of implementation of the Rendezvous (Point Parallel) capability was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments (10-11):____

____

____

____

____

____

____

____

____

12. Was the Intercept set-up capability beneficial? Yes No

13. The ease of implementation of the Intercept capability was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments (12-13):____

____

____

____

____

____

____

14. The operational utility of the Mission Computer approach used in this simulator ___________ mission difficulty/aircrew workload? Why?

a. Substantially decreased
b. Moderately decreased
c. Slightly decreased
d. Did not increase or decrease
e. Slightly increased
f. Moderately increased
g. Substantially increased

Comments :____

____

____

____

15. Were the set-up procedures of the Mission Computer approach understandable and easy to use? Yes No (If no, please explain below.)

Comments :____

____

____

____

16. Were the avionics system power pages understandable and easy to use? Yes No (If no, please explain below.)

Comments :____

____

____

____

Weather Radar System

1. **The location of the radar control panel was ___________.**

    a. Completely unacceptable
    b. Moderately unacceptable
    c. Borderline
    d. Moderately acceptable
    e. Completely acceptable

Comments : ____

____

____

____

2. **Should each pilot be given a separate radar range control to allow for the monitoring of different radar ranges at the same time?** Yes No **Why?**

Comments : ____

____

____

____

3. **Were the various range selections provided adequate for mission accomplishment?** Yes No **Why?**

Comments : ____

____

____

____

4. The radar control panel numbering/lettering/nomenclature was ________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments :____

5. The lighting of the radar control panel was __________ for inflight use?

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments :____

6. Are there any functions not included on the radar control panel that you feel would effectively reduce mission difficulty/aircrew workload?
Yes No **Why?**

Comments:____

7. Should a separate dedicated display be installed for the radar return presentation? Yes No **Why?**

Comments :____

8. Do you feel the need for a weather radar as necessary for mission accomplishment? Yes No **Would a monochrome radar presentation be adequate?** Yes No

Comments :____

9. Do you feel the need still exists for the APN-69? Yes No

Comments :____

10. Do you prefer the Mission Management System (MMS) procedure or the current APN-69 code selectors for setting the beacon code?

a. MMS b. APN-69

Comments :____

11. Do you feel the Air-to-Air tacan capability alone would be sufficient to perform an air refueling rendezvous? Yes No **Why?**

Comments :____

Electronic Horizontal Situation Indicator (EHSI)

1. **The location of the EHSI function control panel was __________ for inflight use?**

    a. Completely unacceptable
    b. Moderately unacceptable
    c. Borderline
    d. Moderately acceptable
    e. Completely acceptable

Comments :____

____

____

____

2. **The readability of the function control panel nomenclature was ________.**

    a. Completely unacceptable
    b. Moderately unacceptable
    c. Borderline
    d. Moderately acceptable
    e. Completely acceptable

Comments :____

____

____

____

3. **The lighting of the function control panel was _______ for inflight use?**

    a. Completely unacceptable
    b. Moderately unacceptable
    c. Borderline
    d. Moderately acceptable
    e. Completely acceptable

Comments :____

____

____

____

4. The location of the map overlay control panel was __________ for inflight use?

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments :____

5. The readability of the map overlay control panel nomenclature was __________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments :____

6. The lighting of the map overlay control panel was __________ for inflight use.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments :____

7. The ability to overlay waypoints, navaids (Tacans/VORs), and airports on the EHSI map display ___________ mission difficulty/aircrew workload?

a. Substantially decreased
b. Moderately decreased
c. Slightly decreased
d. Did not increase or decrease
e. Slightly increased
f. Moderately increased
g. Substantially increased

Comments :____

____

____

____

8. Did you like the capability to display either a full compass rose or an arc segment (60^{o}) individually on the EHSI? Yes No Why?

Comments :____

____

____

____

9. Do you feel the capability to display the selected radio aids on the EHSI display as beneficial? Yes No Why?

Comments :____

____

____

10. The EHSI dimming (brightness) capability was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments :____

____

____

Fuel Savings Advisory/Cockpit Avionics Systems (FSA/CAS)

Integrated Fuel Management Panel (IFMP)

1. The IFMP location in this KC-135 crew station was __________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

2. The size of the integrated fuel management panel was __________.

Too small About right Too large

Comments: ____

3. The size of the switches was __________.

Too small About right Too large

Comments: ____

4. The spacing between switches was ___________.

Too small About right Too large

Comments: ____

____

____

____

5. The readability of the low pressure/low fuel annunciators on the IFMP was _________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

6. The size of the digital fuel quantity/CG indicator was ___________.

Too small About right Too large

Comments: ____

____

____

____

7. The color of the digital fuel quantity/CG readouts was __________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

8. The dimming capability of the digital fuel quantity/CG readouts was __________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

9. The IFMP lighting was __________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

10. The level of workload required to monitor fuel flow and fuel quantity information was ____________.

a. Extremely difficult
b. Moderately difficult
c. Borderline
d. Moderately easy
e. Extremely easy

Comments: ____

____

____

____

11. The overall operational utility of the IFMP is ____________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

12. What suggested changes, if any, would you suggest to make the IFMP easier to operate?

Comments: ____

____

____

____

FSA/CAS ICDU Display Formats

1. The accessibility of the FSA/CAS ICDU display, in context with the other display pages in the menu structure, was ____________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

2. The information presented on this display was ____________. What information should be added/deleted? (Please explain in comments section.)

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

3. The FSA/CAS ICDU display was ____________ to use. What difficulties, if any, were encountered with this unit?

a. Extremely difficult
b. Moderately difficult
c. Borderline
d. Moderately easy
e. Extremely easy

Comments: ____

4. The workload level required to operate the FSA/CAS using the ICDU for fuel management tasks was ___________.

a. Extremely difficult
b. Moderately difficult
c. Borderline
d. Moderately easy
e. Extremely easy

Comments: ____

____

____

____

Remote Display Unit (RDU)

1. The location of the RDU was _________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

2. The size of the RDU command airspeed and altitude digital readouts was ____________.

Too small   About right   Too large

Comments: ____

3. The color of the RDU command airspeed and altitude digital readouts was ____________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

4. The dimming capability of the RDU command airspeed and altitude digital readouts was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

5. What information should be added/deleted from this RDU?

Comments: ____

____

____

____

____

____

____

____

Remote Radio Unit (RRU)

Communication Readouts

1. The operational utility of the RRU was ________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

2. The location of the RRU was __________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

3. The size of the RRU digital readouts was ___________.

Too small　　　About right　　　Too large

Comments: ____

____

____

____

4. The color of the RRU digital readouts was ___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

5. The brightness of the RRU digital readouts was___________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

Ground Mission Planning System (MPS)

1. The existing ground MPS was ___________.

    a. Completely unacceptable
    b. Moderately unacceptable
    c. Borderline
    d. Moderately acceptable
    e. Completely acceptable

Comments: ____

____

____

____

2. To what extent is the aircrew involved in the initial mission planning on the MPS using the Z-248?

Comments: ____

____

____

____

3. What changes, if any, would you make to this system.

Electronic Attitude Director Indicator (EADI)

1. The EADI dimming (brightness) capability was ____________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

2. The location of the EADI Decision Height (DH) set knob was __________ for inflight use.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

3. The letters "DH" appearing in the left center of the EADI when radar altitude went below the decision height setting was ____________. (Please explain below.)

a. Helpful and sufficient
b. Helpful, but not sufficient.
c. Not helpful

Comments: ____

4. The digital presentation for the Decision Height setting was __________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

5. The EADI has digital information displayed for Indicated airspeed (IAS Angle of Attack, Barometric Pressure, Vertical Velocity (VV), and radio altimeter altitude. Please answer Yes (Y) or No (N) to the following questions

Size: Is the size of the information adequate for its application?
Location: Is the location of the information adequate?
Necessity: Is the displayed information necessary or critical?

Information	Size	Location	Necessity
Angle of Attack (AOA)	______	______	______
Barometric Pressure Altitude (B)	______	______	______
Indicated Airspeed (I)	______	______	______
Radio Altitude (RA)	______	______	______
Vertical Velocity (VV)	______	______	______

Comments: ____

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____

6. Should a speed deviation indicator scale be placed onto the EADI?

a. Yes, it would be very helpful.
b. Yes, it would be moderately helpful.
c. Yes, it would be somewhat helpful.
d. No, it would not be at all helpful.

Comments: ____

____

____

____

7. The size of the EADI was ________________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

8. The colors used for the EADI were __________________.

a. Completely unacceptable
b. Moderately unacceptable
c. Borderline
d. Moderately acceptable
e. Completely acceptable

Comments: ____

____

____

____

9. Identify any specific changes you might have concerning the EADI:

Comments: ____